SPP Southwest Power Pool

Impact Study for Generation Interconnection Request GEN–2002–006

SPP Tariff Studies
(#GEN-2002-006)
September 2008

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-2002-006. 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 interconnection request has been studied with Suzlon, Mitsubishi, GE, and Clipper wind turbines.

Power Factor Requirements

Order #661A Power Factor requirements were determined in the following manner. The wind farm was modeled at the Texas County bus. A var generator was modeled at the 115kV bus to maintain a 1.0 pu voltage. Various outages were modeled for the winter and summer season. The worst case outage was found to be for the Hansford – Spearman 115kV line. The wind farm was found to need to maintain a unity power factor for this outage.

Season	Outage	Wind Farm MW	Wind Farm Mvar	Power Factor at POI
Winter	Hansford – Spearman 115kV	143.9 MW	8.9 Mvar	99.8% leading (producing vars)
Summer	Hansford – Spearman 115kV	144.3 MW	24.9 Mvar	98.5% leading (producing vars)

Interconnection Facilities

The Impact Study has determined that differing reactive compensation requirements are necessary depending on the turbine selected.

For the General Electric turbines, no capacitor banks are required with the inclusion of the GE Windvar system to be included with the wind turbines.

For the Suzlon turbines, a 30.8 Mvar of capacitors are required to maintain at least a unity power factor. Also, a STATCOM with a short time rating of +/-10 MVA is required for installation of the Suzlon turbines to meet FERC Order #661A low voltage ride through provisions. If the interconnection of the wind farm is delayed until after SPS has constructed the “Hitchland Upgrades” as defined in the body of this report, the STATCOM device is not necessary.

For the Clipper turbines, the Customer must meet a unity power factor requirement. The Impact Study has sized a capacitor bank assuming the Clipper turbines are operating at unity.

However, the Customer may determine if the reactive capability of the Clipper turbines can be used to compensate for reactive losses in the transformer and collector system.

For the Mitsubishi turbines, the Customer must meet a unity power factor requirement.
The Impact Study has sized a capacitor bank assuming the Mitsubishi turbines are operating at unity. However, the Customer may determine if the reactive capability of the Clipper turbines can be used to compensate for reactive losses in the transformer and collector system.

Final Report

For

Southwest Power Pool

From

S&C Electric Company

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2002-006

S&C Project No. 3063

September 14, 2008

S&C Electric Company

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Executive Summary

This system impact study was performed in response to a generation interconnection study request through the Southwest Power Pool Tariff for a 150 MW wind farm in Texas County, Oklahoma. The Wind Project will interconnect into the existing 115 kV Texas County Interchange and the SPP footprint will be displaced. The objective of this study was to determine the impact of the interconnection on the stability of nearby areas and prior queued projects for seasonal winter peak (with facilities planned for 2008) and summer peak (with facilities planned for 2012) cases evaluating four different makes of wind turbine generators available in the market: GE 1.5 MW, Suzlon S88 2.1 MW, Mitsubishi MWT-95 2.4 MW, and Clipper C93 2.5 MW. Present Wind Projects must comply with low-voltage ride through provisions in FERC Order 661A. Steady-state and dynamic studies were performed at full load.

With exception of the Suzlon wind turbine generators, all studies were performed without the Southwest Public Service (SPS) Hitchland transmission reliability upgrade project planned for the year 2010. The Hitchland upgrades will consist of the following additions:

- 230 kV line from Pringle to Hitchland
- 230 kV line from Moore County to Hitchland
- 230/115 kV transformer at Hitchland
- 345/230/13.2 kV transformer at Hitchland
- 115 kV line from Hitchland to Sherman Tap
- 115 kV line from Hitchland to Texas County
- 115 kV line from Hitchland to Dalhart
- Relocation of GEN-2006-020 to the new 115 kV Hitchland to Sherman Tap line

SPP requires the project to maintain unity power factor at the POI under normal operating conditions. The GE wind turbine option will require a Wind Farm Management System (WFMS) to dynamically control the power factor setpoint of the wind turbine generators to compensate for transmission, collector and transformation losses in response to nearby transmission grid changes and variations in wind farm production levels. Suzlon, Mitsubishi, and Clipper wind turbine options will require the installation of additional mechanically switched shunt capacitors (MSSC) at the 34.5 kV collector bus with fixed power factor setpoint at each wind turbine generator of unity. MSSC's should be divided in appropriately sized steps and switched on and off automatically in response to transmission grid changes and variations in wind farm production levels to maintain unity power factor at the POI. The

requirement is for 30.8 MVAR of MSSC's with the Suzlon option, 21.6 MVAR of MSSC's with the Mitsubishi option, and 30.8 MVAR of MSSC's with the Clipper option.

Three-phase and single-phase-to-ground faults were studied at locations specified by SPP. Dynamic stability results utilizing GE, Mitsubishi and Clipper wind turbine generators indicate that nearby areas remain stable for all fault contingencies; however, GEN-2006-020 will unintentionally be islanded and the Vestas V80 wind turbine generators trip off for faults on the Texas County to Sherman Tap 115 kV line. No action items are required at this point to keep GEN-2006-020 connected since the same outcome has been observed in the pre-project case. The interconnecting project will satisfy low-voltage ride through provisions in FERC Order 661A.

Studies performed prior to the Hitchland transmission reliability upgrade project with the Suzlon S88 wind turbine generators indicate that wind turbine generators will have degraded performance post-fault for permanent three-phase and single-phase-to-ground faults on the Hansford to Spearman 115kV line, near Hansford. Suzlon wind turbine generators consume reactive power post-fault, results suggest, causing terminal voltages to settle at around 0.90 pu. Real and reactive power exhibit significant amount of control chatter and unstable oscillations, and the output power cannot return to rated output level. Both the project and GEN-2002-009 use Suzlon S88 2.1 MW wind turbine generators and exhibit the same problems.

Post Hitchland upgrades, the local system strength is improved and no degraded performance is observed from the Suzlon wind turbine generators.

The temporary solution before the Hitchland project is in place is the addition of a STATCOM located at the 34.5 kV collector bus of GEN-2002-00 with minimum 2-second short-time rating of 10 MVA. This will provide the fast and continuous reactive power needs of the Suzlon wind turbine generators at GEN-2002-006 and GEN-2002-009, which will help voltages settle above 0.90 pu, prevent control chatter and oscillations, and help the real power to recover to rated output power.

1. Introduction

This system impact study was performed in response to a generation interconnection study request through the Southwest Power Pool Tariff for a 150 MW wind farm in Texas County, Oklahoma. The Wind Project will interconnect into the existing 115 kV Texas County Interchange and the SPP footprint will be displaced.

The objective of this study was to determine the impact of the interconnection on the stability of nearby areas and prior queued projects for seasonal winter peak (with facilities planned for 2008) and summer peak (with facilities planned for 2012) cases evaluating four different wind turbine generators makes available in the market: GE 1.5 MW, Suzlon S88 2.1 MW, Mitsubishi MWT-95 2.4 MW, and Clipper C93 2.5 MW.

Present Wind Projects must comply with low-voltage ride through provisions in FERC Order 661A. Steady-state and dynamic studies were performed at full load.

2. Load Flow Model

Collector system layout and collector impedance information for each type of wind turbine were provided for each type of wind turbine generator studied. Wind turbine generators from feeder circuits were represented as aggregated generators to simplify representation in PSS/E. Impedance calculations and parameters for each wind turbine type are included in Appendix A. Parameters for the 115 kV, 397.5 ACSR transmission line were not available at the time of the study, but after consultation with SPP, typical transmission line characteristics as summarized in Table 1 were used for the wind project model.

Table 1: 115 kV Transmission Line Parameters

Description	Parameters
397.5 ACSR, 6.5 miles, SC-ST, 24 feet equivalent spacing	Z1 = 0.01273 + 0.040332j p.u. on 100 MVA base B1 = 0.004410595 p.u. on 100 MVA base

The addition of the project to the base case will require a number of changes to transformer tap settings on prior queued projects as summarized in Table 2.

Table 2: Transformer no-load fixed tap settings at prior-queued projects

Case	GEN-2006-020 main (tap setting in %)	GEN-2002-008 main (tap setting in %)	GEN-2002-009 main (tap setting in %)
Pre-project	100	100	100
Post-project – GE	102.5	105	102.5
Post-project – Suzlon	102.5	105	102.5
Post-project – Mitsubishi	102.5	105	102.5
Post-project – Clipper	102.5	105	102.5

2.1. Modeling of Wind Turbine Generators in Load Flow

General Electric 1.5 MW Wind Turbine Generators

SPP requires the project to maintain unity power factor at the POI under normal operating conditions through the use of a Wind Farm Management System (WFMS) to dynamically control the power factor setpoint of wind turbine generators to compensate for collector and transformation losses in response to nearby transmission grid changes and variations in wind farm production levels in order to maintain unity power factor at the POI. Mechanically switched capacitor banks will not be required either at 34.5 kV or 161 kV. The power factor at each wind turbine generator was manually adjusted to 0.98 lagging (capacitive) to achieve zero exchange at the POI.

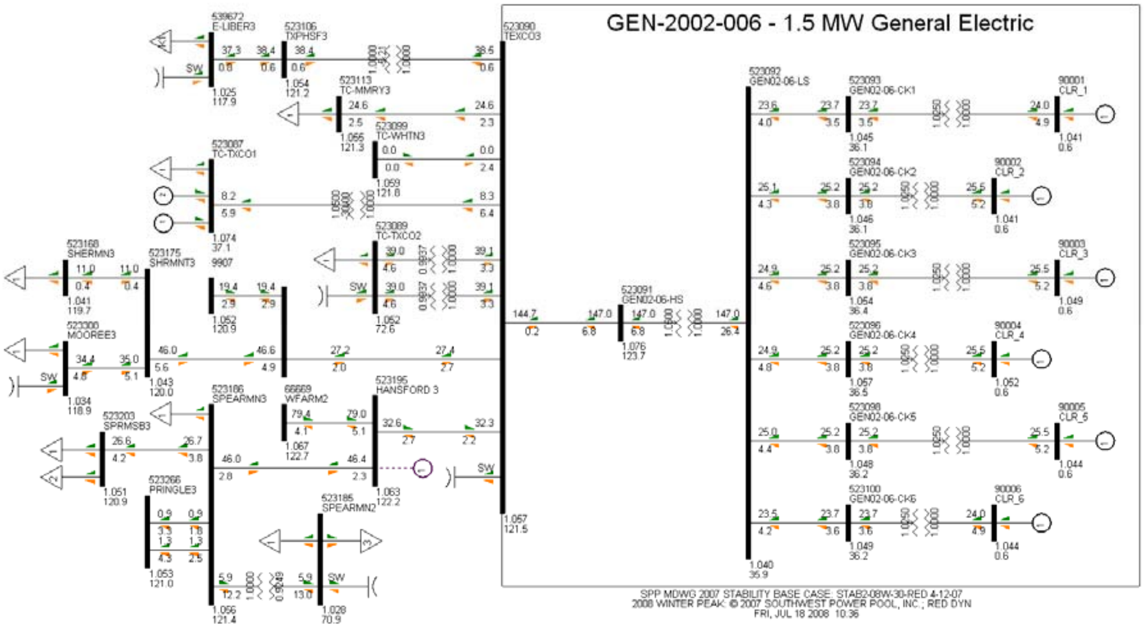

Figure 1: GEN-2002-006 (GE 1.5 MW) and nearby buses for winter peak 2008

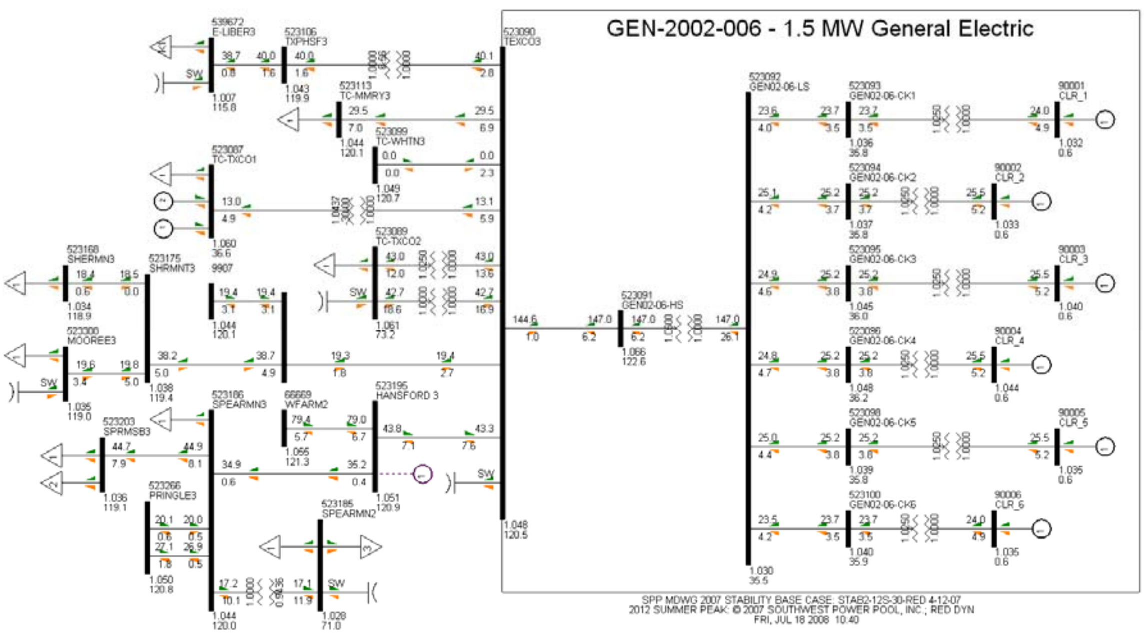

Figure 2: GEN-2002-006 (GE 1.5 MW) and nearby buses for summer peak 2012

Suzlon S88 2.1 MW Wind Turbine Generators

Suzlon S88 2.1 MW wind turbine generators have power factor setting range of 0.92 leading (inductive) to 0.9995 lagging (capacitive) at rated power output. In order to satisfy the unity power factor requirement at the POI, additional 30.6 MVAR of mechanically switched shunt capacitors (MSSC) are required at the 34.5 kV collector bus. MSSC's should be divided in appropriately sized steps and switched on and off automatically.

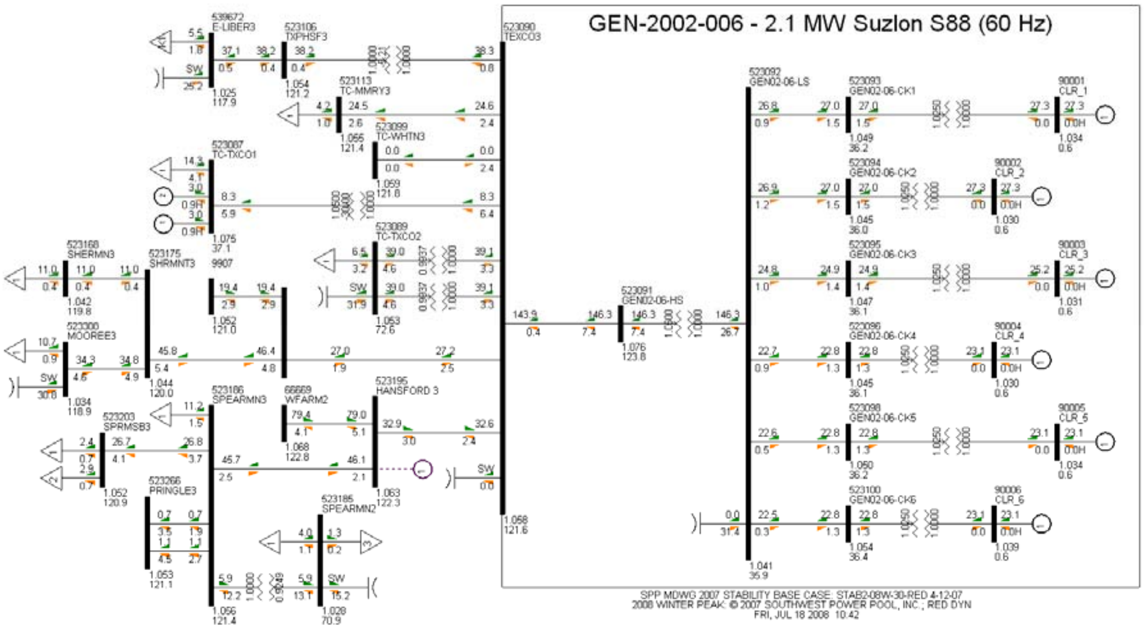

Figure 3: GEN-2002-006 (Suzlon 2.1 MW) and nearby buses for winter peak 2008

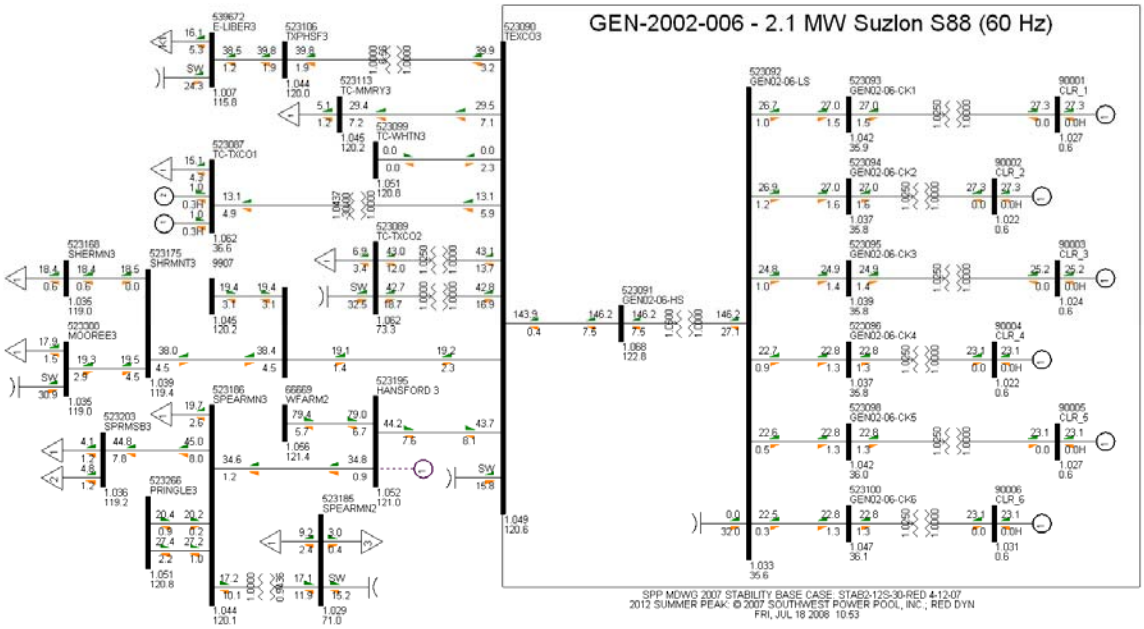

Figure 4: GEN-2002-006 (Suzlon 2.1 MW) and nearby buses for summer peak 2012

Mitsubishi MWT-95 2.4 MW Wind Turbine Generators

Mitsubishi MWT-95 2.4 MW wind turbine generators have fixed power factor setting range of 0.90 leading (inductive) to 0.95 lagging (capacitive). The power factor is set to unity. In order to satisfy the unity power factor requirement at the POI, additional 21.6 MVAR of mechanically switched shunt capacitors (MSSC) are required at the 34.5 kV collector bus. Standard with each MWT-95 turbine is a permanently connected shunt capacitors at 0.69 kV of 0.11 MVAR. MSSC's should be divided in appropriately sized steps and switched on and off automatically.

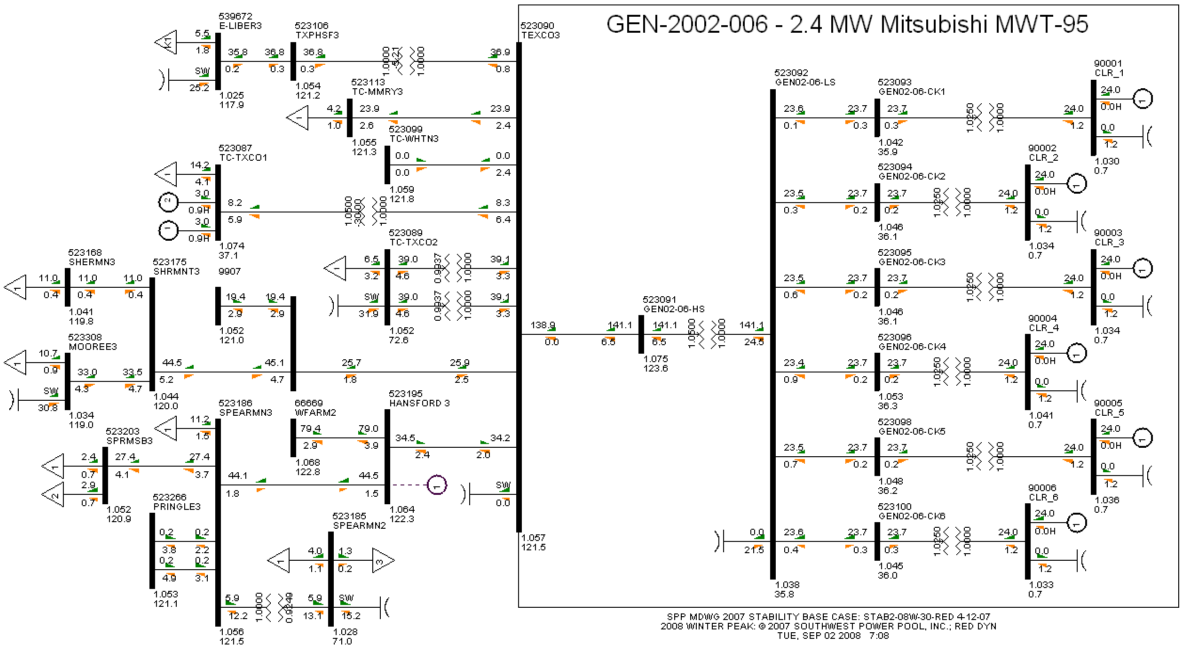

Figure 5: GEN-2002-006 (MHI 2.4 MW) and nearby buses for winter peak 2008

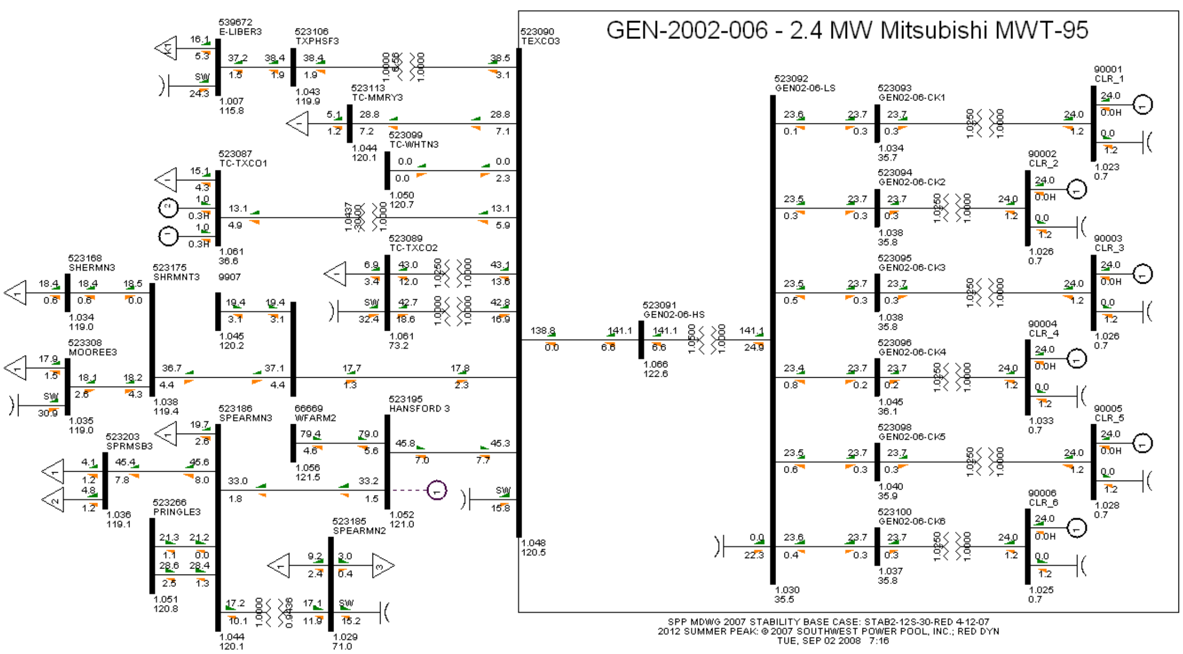

Figure 6: GEN-2002-006 (MHI 2.4 MW) and nearby buses for summer peak 2012

Clipper C93 2.5 MW Wind Turbine Generators

Clipper C93 2.5 MW wind turbine generators have fixed power factor setting range of 0.95 leading (inductive) to 0.95 lagging (capacitive). The power factor is set to unity. In order to satisfy the unity power factor requirement at the POI, additional 30.6 MVAR of mechanically switched shunt capacitors (MSSC) are required at the 34.5 kV collector bus. MSSC's should be divided in appropriately sized steps and switched on and off automatically.

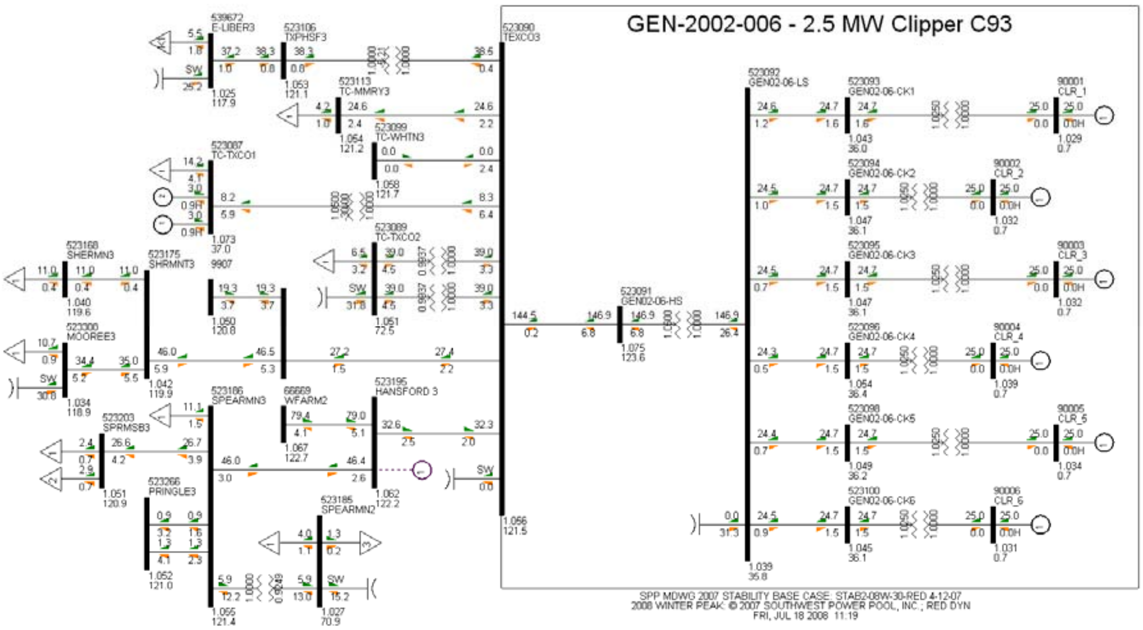

Figure 7: GEN-2002-006 (Clipper 2.5 MW) and nearby buses for winter peak 2008

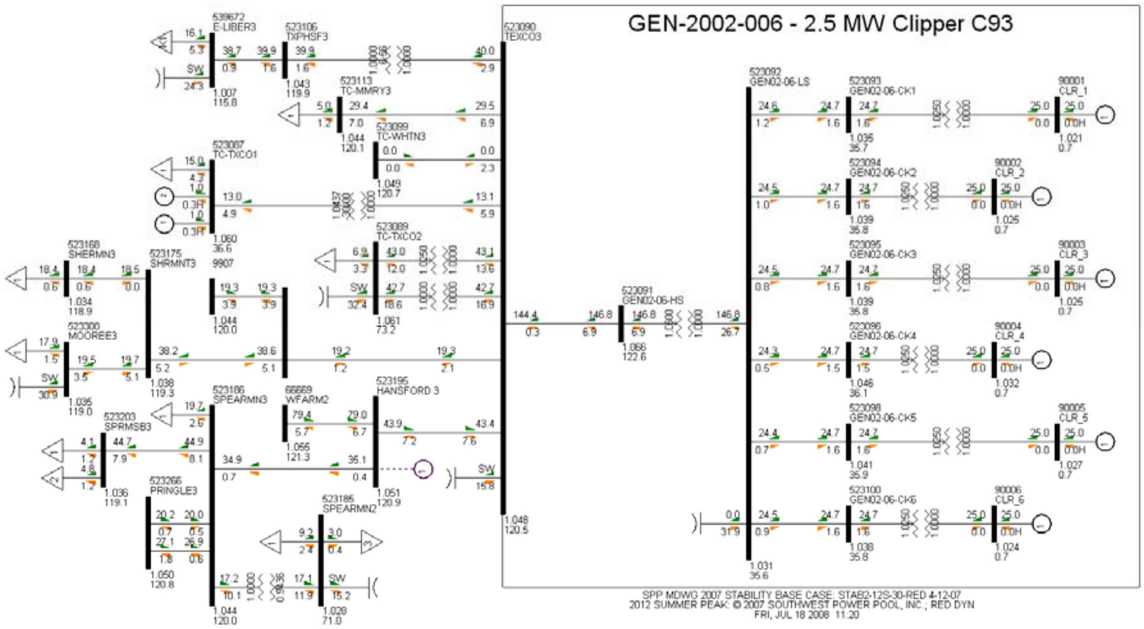

Figure 8: GEN-2002-006 (Clipper 2.5 MW) and nearby buses for summer peak 2012

Table 3: Transformer no-load fixed tap settings within the project

Transformer	Tap setting in %
Main 34.5/115 kV	105
WTG GSU	102.5

Table 4: MSSC requirements at full load

Case	MVAR at 34.5 kV
Post-project – GE	None
Post-project – Suzlon	30.6
Post-project – Mitsubishi	21.6
Post-project – Clipper	30.6

3. Dynamic Stability Analysis

Dynamic simulations were performed for fault contingencies in Table 5 with and without GEN-2002-006.

Table 5: Fault Contingencies Evaluated

Cont. No.	*Cont. Name*	*Description*
1	*FLT13PH*	3 phase fault on the Texas County (523090) to Sherman Tap (523175) 115kV line, near Texas County. a. Apply fault at Texas County. b. Clear fault after 5 cycles by tripping the line from Texas County to Sherman Tap.
2	FLT21PH	*Single phase fault and sequence like Cont. No. 1*
3	*FLT33PH*	3 phase fault on the Texas County (523090) to Hansford (523195) 115kV line, near Texas County. a. Apply fault at Texas County. b. Clear fault after 5 cycles by tripping the line from Texas County to Hansford 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 Texas County (523090) to TC-MMRY (523113) 115kV line, near Texas County. a. Apply fault at Texas County. b. Clear fault after 5 cycles by tripping the line from Texas County to TC-MMRY c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
6	FLT61PH	*Single phase fault and sequence like Cont. No. 5*
7	*FLT73PH*	3 phase fault on the Hansford (523195) to Spearman (523186) 115kV line, near Hansford. a. Apply fault at Hansford. b. Clear fault after 5 cycles by tripping the line from Spearman to Hansford c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
8	FLT81PH	*Single phase fault and sequence like Cont. No. 7*
9	FLT93PH	3 phase fault on the Spearman (523186) to Pringle (523266) 115kV line, near Pringle. a. Apply fault at Pringle. b. Clear fault after 5 cycles by tripping the line from Spearman to Pringle 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 E Liberal (539672) – Texas County Phase Shifter 115kV line (523106) line, near E Liberal. a. Apply fault at E Liberal. b. Clear fault after 5 cycles by tripping the line from E Liberal to Texas County Phase Shifter 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.

Cont. No.	*Cont. Name*	*Description*
12	FLT121PH	*Single phase fault and sequence like Cont. No.119*
13	FLT133PH	3 phase fault on the Moore County (523308) – Sherman County Tap (523168) 115kV line (523106) line, near Moore County. a. Apply fault at Moore County. b. Clear fault after 5 cycles by tripping the line from Moore County to Sherman County Tap
14	FLT141PH	*Single phase fault and sequence like Cont. No.13*

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 an approximate 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, Westplains Energy

Prior queued projects monitored:

- GEN-2002-008; 240MW of GE turbines on the Potter – Finney 345kV line
- GEN-2002-009; 80MW of Suzlon turbines on the Texas County – Spearman 115kV line
- GEN-2003-020; 160MW of GE turbines at Carson County substation
- GEN-2006-020; 20MW of Vestas V80 wind turbines on the Texas County – Sherman 115kV line

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

General Electric 1.5 MW Wind Turbine Generators

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 6.

Table 6: 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

Suzlon S88 2.1 MW Wind Turbine Generators

The Suzlon S88 2.1 MW/60 Hz wind turbine generators are variable slip with electrical pitch system. The manufacturer provides 14 steps of capacitor banks intended for local power factor control. At full load, the wind turbine generator can operate between 0.92 inductive to 0.9995 capacitive power factor. The PSS/E model of the Suzlon wind turbine generator comes with built-in protection package. Voltage and frequency relay settings are summarized in Table 7.

Table 7: Suzlon S88 2.1 MW/60 Hz wind turbine generator trip settings

Grid Voltage and Frequency Protection					
Relay trips if |Vbus|<	90%		UV Relay 1	0.90	Pu
for t =	60	s		60.00	S
Relay trips if |Vbus|<	80%		UV Relay 2	0.80	Pu
for t =	2.8	s		2.80	S
Relay trips if |Vbus|<	60%		UV Relay 3	0.60	Pu
for t =	1.6	s		1.60	S
Relay trips if |Vbus|<	40%		UV Relay 4	0.40	Pu
for t =	0.7	s		0.70	S
Relay trips if |Vbus|<	15%		UV Relay 5	0.15	Pu
for t =	0.08	s		0.08	S
Relay trips if |Vbus|>	115%		OV Relay 1	1.15	Pu
for t =	60	s		60.00	S
Relay trips if |Vbus|>	120%		OV Relay 2	1.20	Pu
for t =	0.08	s		0.08	S
Relay trips if Fbus <	57	Hz	UF Relay 1	0.95	Pu
for t =	0.2	s		0.20	S
Or Fbus <	63	Hz	OF Relay 1	1.05	Pu
for t =	0.2	s		0.20	S

Mitsubishi MWT-95 2.4 MW Wind Turbine Generators

The wind turbine generator will engage in Network Voltage Drop Help (NDH) when terminal voltages of the MWT-95 are outside of 0.9 pu to 1.1 pu. Reactive power output takes priority over real power to meet short-time reactive power demands. In steady-state, the NDH will not be active and active power will take priority over reactive power. To protect the wind turbine generator from damaging high fault current, the rotor is shorted during crowbar protection. The PSS/E model of the MWT-95 wind turbine generator comes with a protection package. Voltage and frequency relay settings of the MWT-95 are summarized in Table 8.

Table 8: Mitsubishi MWT-95 trip settings

Relay type	Description	Trip setting and time delay	units
Undervoltage (27-1)	Relay trips if |Vbus|<	0.90	pu
	for t =	3.00	s
Undervoltage (27-2)	Relay trips if |Vbus|<	0.85	pu
	for t =	2.842	s
Undervoltage (27-3)	Relay trips if |Vbus|<	0.75	pu
	for t =	2.525	s
Undervoltage (27-4)	Relay trips if |Vbus|<	0.65	pu
	for t =	2.208	s
Undervoltage (27-5)	Relay trips if |Vbus|<	0.55	pu
	for t =	1.892	s
Undervoltage (27-6)	Relay trips if |Vbus|<	0.45	pu
	for t =	1.575	s
Undervoltage (27-7)	Relay trips if |Vbus|<	0.35	pu
	for t =	1.258	s
Undervoltage (27-8)	Relay trips if |Vbus|<	0.25	pu
	for t =	0.942	s
Undervoltage (27-9)	Relay trips if |Vbus|<	0.20	pu
	for t =	0.783	s
Undervoltage (27-10)	Relay trips if |Vbus|<	0.025	pu
	for t =	0.15	s
Overvoltage (59-1)	Relay trips if |Vbus|>	1.10	pu
	for t =	0.020	s
Overfrequency (81O)	Relay trips if Fbus >	61.00	Hz
	for t =	0.30	s
Underfrequency (81U)	Relay trips if Fbus <	59.00	Hz
	for t =	0.30	s

Clipper C93 2.5 MW Wind Turbine Generators

The PSS/E model of the Clipper wind turbine generator comes with built-in protection package. Voltage and frequency relay settings are summarized in Table 9.

Table 9: Clipper Windpower Liberty Series Wind Turbine trip settings

Relay type	Description	Trip setting and time delay	units
1st Undervoltage (27-1)	Relay trips if |Vbus|<	0.90	pu
	for t =	3.00	s
2nd Undervoltage (27-2)	Relay trips if |Vbus|<	0.10	pu
	for t =	0.10	s
1st Overvoltage (59-1)	Relay trips if |Vbus|>	1.10	pu
	for t =	5.00	s
2nd Overvoltage (59-2)	Relay trips if |Vbus|>	1.20	pu
	for t =	0.50	s
3rd Overvoltage (59-3)	Relay trips if |Vbus|>	1.30	pu
	for t =	0.10	s
Overfrequency (81O)	Relay trips if Fbus >	63.00	Hz
	for t =	0.10	s
Underfrequency (81U)	Relay trips if Fbus <	57.00	Hz
	for t =	0.10	s

3.3. Pre-Project Dynamic Simulations

Non-disturbance runs were carried out on the Winter Peak 2008 and Summer Peak 2012 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 5 for winter 2008 and summer 2012 peak cases. GEN-2006-020 will unintentionally be islanded and the Vestas V80 wind turbine generators trip off for faults on the Texas County to Sherman Tap 115kV line (fault #1 and #2 from Table 5). Results are summarized on Table 10.

Table 10: Pre-project stability analysis results

Fault No.	Description	Winter Peak 2008	Summer Peak 2012
1	3 phase fault on the Texas County (523090) to Sherman Tap (523175) 115kV line, near Texas County.	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)
2	*Single phase fault and sequence like Cont. No. 1*	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)
3	3 phase fault on the Texas County (523090) to Hansford (523195) 115kV line, near Texas County.	STABLE	STABLE
4	*Single phase fault and sequence like Cont. No. 3*	STABLE	STABLE
5	3 phase fault on the Texas County (523090) to TC-MMRY (523113) 115kV line, near Texas County.	STABLE	STABLE
6	*Single phase fault and sequence like Cont. No. 5*	STABLE	STABLE
7	3 phase fault on the Hansford (523195) to Spearman (523186) 115kV line, near Hansford.	STABLE	STABLE
8	*Single phase fault and sequence like Cont. No. 7*	STABLE	STABLE
9	3 phase fault on the Spearman (523186) to Pringle (523266) 115kV line, near Pringle.	STABLE	STABLE

Fault No.	*Description*	Winter Peak 2008	Summer Peak 2012
10	*Single phase fault and sequence like Cont. No.9*	STABLE	STABLE
11	3 phase fault on the E Liberal (539672) – Texas County Phase Shifter 115kV line (523106) line, near E Liberal.	STABLE	STABLE
12	*Single phase fault and sequence like Cont. No.11*	STABLE	STABLE
13	3 phase fault on the Moore County (523308) – Sherman County Tap (523168) 115kV line (523106) line, near Moore County.	STABLE	STABLE
14	*Single phase fault and sequence like Cont. No.13*	STABLE	STABLE

3.4 Post-Project Dynamic Simulations

Non-disturbance runs 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.

Nearby areas are stable for the fault contingencies in Table 5 in winter 2008 and summer 2012 peak cases using the GE, Mitsubishi and Clipper wind turbine generators. GEN-2006-020 will unintentionally be islanded and the Vestas V80 wind turbine generators trip off for faults on the Texas County to Sherman Tap 115 kV line (fault #1 and #2 from Table 5). No action items are required at this point to keep GEN-2006-020 connected since the same outcome has been observed in the pre-project case. Study results with GE, Mitsubishi and Clipper wind turbine generators are summarized in Table 11.

Table 11: Post-project stability analysis results with GE 1.5 MW, Mitsubishi MWT-95 2.4 MW, and Clipper C93 2.5 MW turbines

Fault	Description	GE 1.5 MW		Mitsubishi MWT-95 2.4 MW		Clipper C93 2.5 MW	
		Winter Peak 2008	Summer Peak 2012	Winter Peak 2008	Summer Peak 2012	Winter Peak 2008	Summer Peak 2012
1	3 phase fault on the Texas County (523090) to Sherman Tap (523175) 115kV line, near Texas County.	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)
2	*Single phase fault and sequence like Cont. No. 1*	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)
3	3 phase fault on the Texas County (523090) to Hansford (523195) 115kV line, near Texas County.	STABLE	STABLE	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 Texas County (523090) to TC-MMRY (523113) 115kV line, near Texas County.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
6	*Single phase fault and sequence like Cont. No. 5*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
7	3 phase fault on the Hansford (523195) to Spearman (523186) 115kV line, near Hansford.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
8	*Single phase fault and sequence like Cont. No. 7*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
9	3 phase fault on the Spearman (523186) to Pringle (523266) 115kV line, near Pringle.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
10	*Single phase fault and sequence like Cont. No.9*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

11	3 phase fault on the E Liberal (539672) – Texas County Phase Shifter 115kV line (523106) line, near E Liberal.	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 Moore County (523308) – Sherman County Tap (523168) 115kV line (523106) line, near Moore County.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
14	*Single phase fault and sequence like Cont. No.13*	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Study results with Suzlon wind turbine generators are summarized on Table 12.

Studies performed with the Suzlon S88 wind turbine generators indicate that the wind turbine generators will have degraded performance post-fault for permanent three-phase and single-phase-to-ground faults on the Hansford to Spearman 115kV line, near Hansford (fault #7 and #8 from Table 5). The Suzlon wind turbine generators consume reactive power post-fault, results suggest, causing terminal voltages to settle at around 0.90 pu. Real and reactive power exhibit significant amount of control chatter and unstable oscillations, and the output power cannot return to rated output level. The reasons for the degraded performance may also be due to problems with the Suzlon S88 PSS/E dynamic model. Both the project and GEN-2002-009 will have the same problems.

The addition of a STATCOM located at the 34.5 kV collector bus of GEN-2002-006 with minimum 2-second short-time rating of 10 MVA will address the fast and continuous reactive power needs of the Suzlon wind turbine generators at GEN-2002-006 and GEN-2002-009, which will allow voltages to settle above 0.90 pu, prevent control chatter and oscillations, and allow real power to recover to rated output power.

Figure 9 shows the terminal voltage at each feeder circuit in the project for fault #7 without STATCOM. Figure 10 shows the Suzlon performance for wind turbine generators belonging to feeder 3 in the project for fault #7 without STATCOM.
Figure 11 shows the STATCOM output at rated 34.5 kV voltage for fault #7.
Figure 12 shows the terminal voltage at each feeder circuit in the project for fault #7 with STATCOM. Figure 13 shows the Suzlon performance for wind turbine generators belonging to feeder 3 in the project for fault #7 with STATCOM.

Hitchland transmission reliability upgrade project

The previous cases were studied without the Southwest Public Service (SPS) Hitchland transmission reliability upgrade project planned for the year 2010. The Hitchland upgrades will consist of the following additions:

- 230 kV line from Pringle to Hitchland
- 230 kV line from Moore Co. to Hitchland
- 230/115 kV transformer at Hitchland
- 345/230/13.2 kV transformer at Hitchland
- 115 kV line from Hitchland to Sherman Tap
- 115 kV line from Hitchland to Texas County
- 115 kV line from Hitchland to Dalhart
- Relocation of GEN-2006-020 to the new 115 kV Hitchland to Sherman Tap line

Post Hitchland upgrades, the local system strength is improved and no degraded performance is observed from the Suzlon wind turbine generators.

Figure 14 shows the terminal voltage at each feeder circuit in the project for fault #7 post Hitchland project.
Figure 15 shows the Suzlon performance for wind turbine generators belonging to feeder 3 in the project for fault #7 post Hitchland project.

Table 12: Post-project stability analysis results with Suzlon S88 2.1 MW turbines

Fault	Description	Winter Peak 2008		Summer Peak 2012	
		without STATCOM	with +/- 10 MVAR STATCOM	without STATCOM	with +/- 10 MVAR STATCOM
1	3 phase fault on the Texas County (523090) to Sherman Tap (523175) 115kV line, near Texas County.	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)
2	*Single phase fault and sequence like Cont. No. 1*	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)	STABLE (GEN-2006-020 is unintentionally islanded and trips off)
3	3 phase fault on the Texas County (523090) to Hansford (523195) 115kV line, near Texas County.	STABLE	STABLE	STABLE	STABLE
4	*Single phase fault and sequence like Cont. No. 3*	STABLE	STABLE	STABLE	STABLE
5	3 phase fault on the Texas County (523090) to TC-MMRY (523113) 115kV line, near Texas County.	STABLE	STABLE	STABLE	STABLE
6	*Single phase fault and sequence like Cont. No. 5*	STABLE	STABLE	STABLE	STABLE
7	3 phase fault on the Hansford (523195) to Spearman (523186) 115kV line, near Hansford.	INSTABLE (GEN-2002-006 and GEN-2002-009 low post-fault voltages, P and Q output chatter and oscillations, P cannot return to rated output)	STABLE	INSTABLE (GEN-2002-006 and GEN-2002-009 low post-fault voltages, P and Q output chatter and oscillations, P cannot return to rated output)	STABLE

8	*Single phase fault and sequence like Cont. No. 7*	INSTABLE (GEN-2002-006 and GEN-2002-009 low post-fault voltages, P and Q output chatter and oscillations, P cannot return to rated output)	STABLE	INSTABLE (GEN-2002-006 and GEN-2002-009 low post-fault voltages, P and Q output chatter and oscillations, P cannot return to rated output)	STABLE
9	3 phase fault on the Spearman (523186) to Pringle (523266) 115kV line, near Pringle.	STABLE	STABLE	STABLE	STABLE
10	*Single phase fault and sequence like Cont. No.9*	STABLE	STABLE	STABLE	STABLE
11	3 phase fault on the E Liberal (539672) – Texas County Phase Shifter 115kV line (523106) line, near E Liberal.	STABLE	STABLE	STABLE	STABLE
12	*Single phase fault and sequence like Cont. No.11*	STABLE	STABLE	STABLE	STABLE
13	3 phase fault on the Moore County (523308) – Sherman County Tap (523168) 115kV line (523106) line, near Moore County.	STABLE	STABLE	STABLE	STABLE
14	*Single phase fault and sequence like Cont. No.13*	STABLE	STABLE	STABLE	STABLE

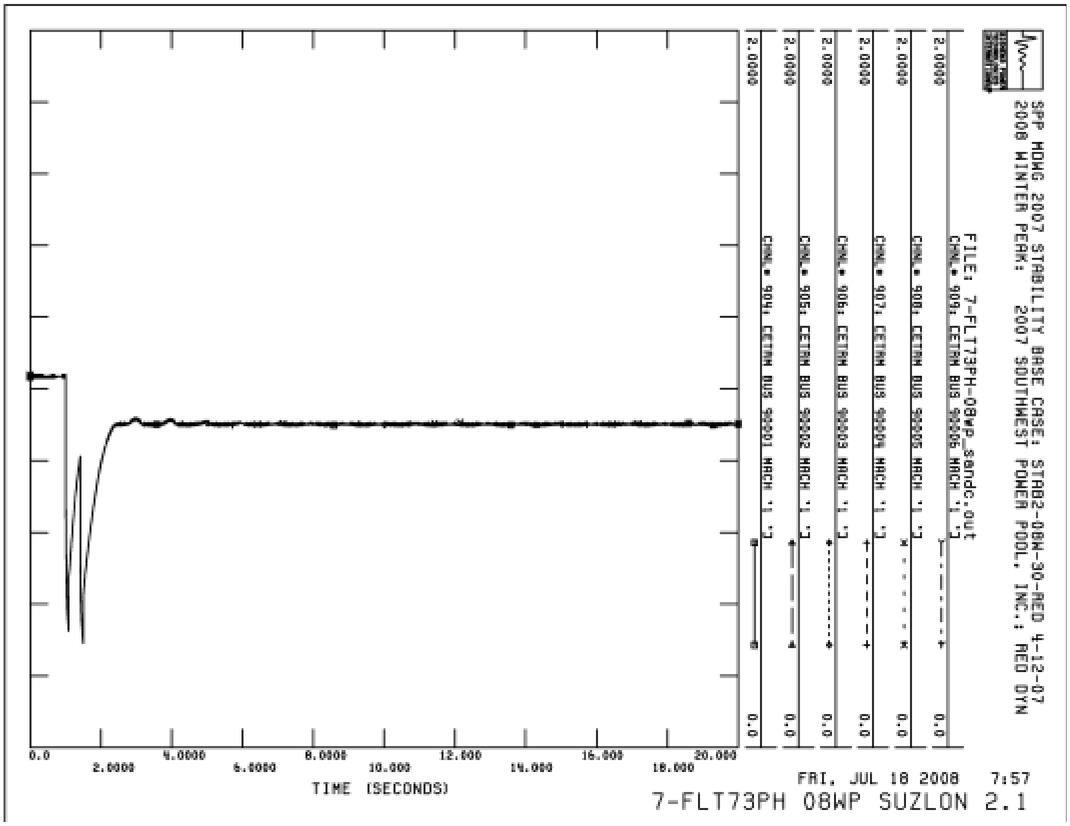

Figure 9: Suzlon terminal voltages for fault #7 without STATCOM (winter peak)

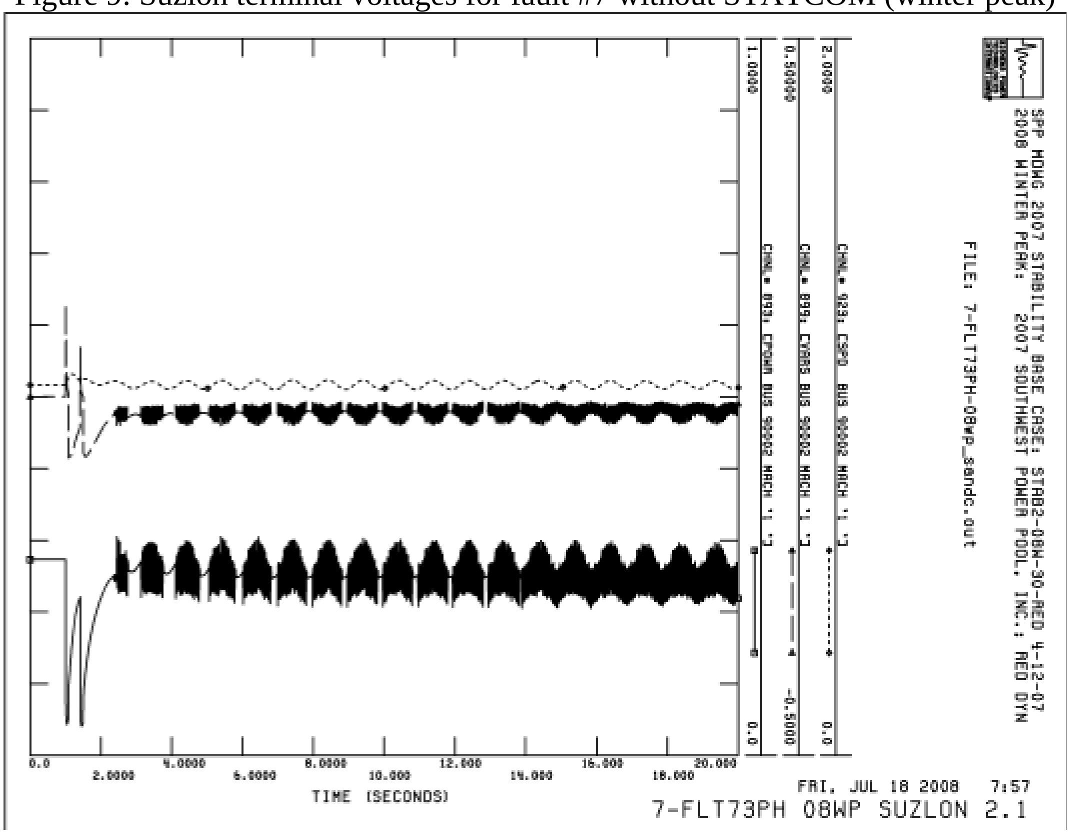

Figure 10: Suzlon performance (circuit 3) for fault #7 without STATCOM (winter peak)

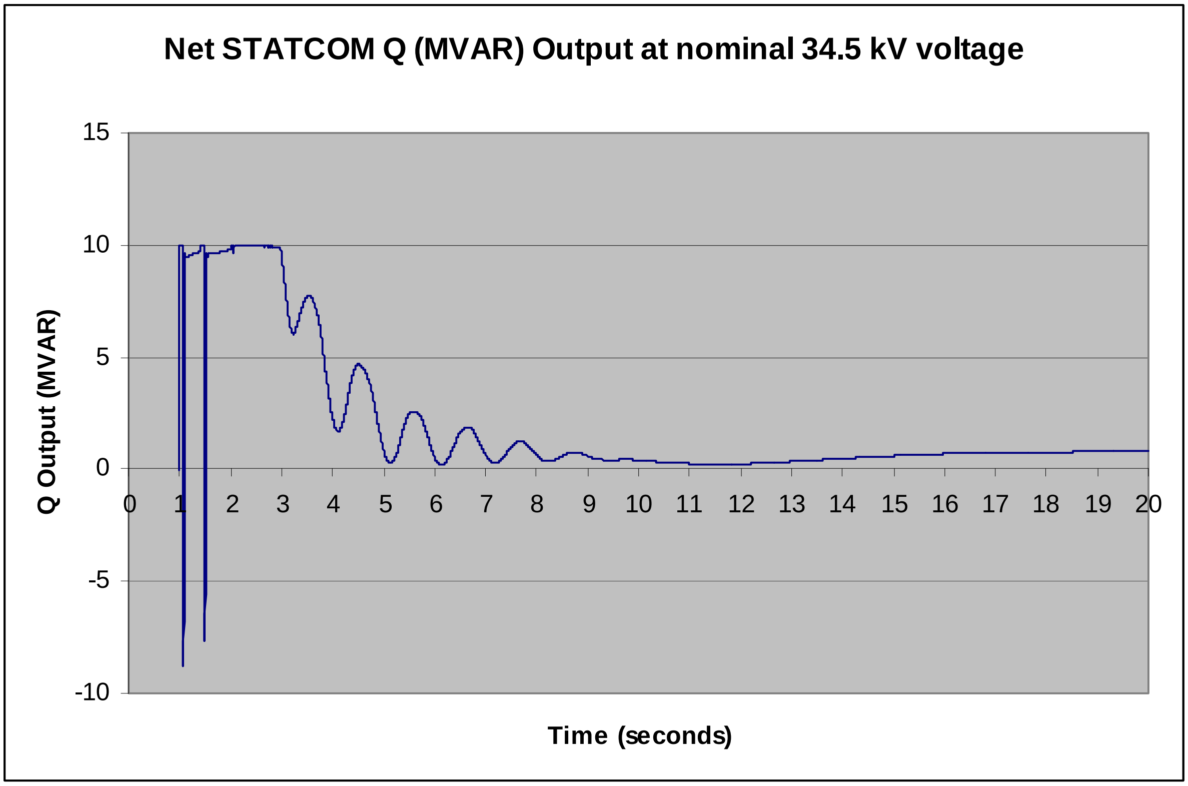

Figure 11: Net STATCON Q output at rated 34.5 kV voltage for fault #7 (Table 5)

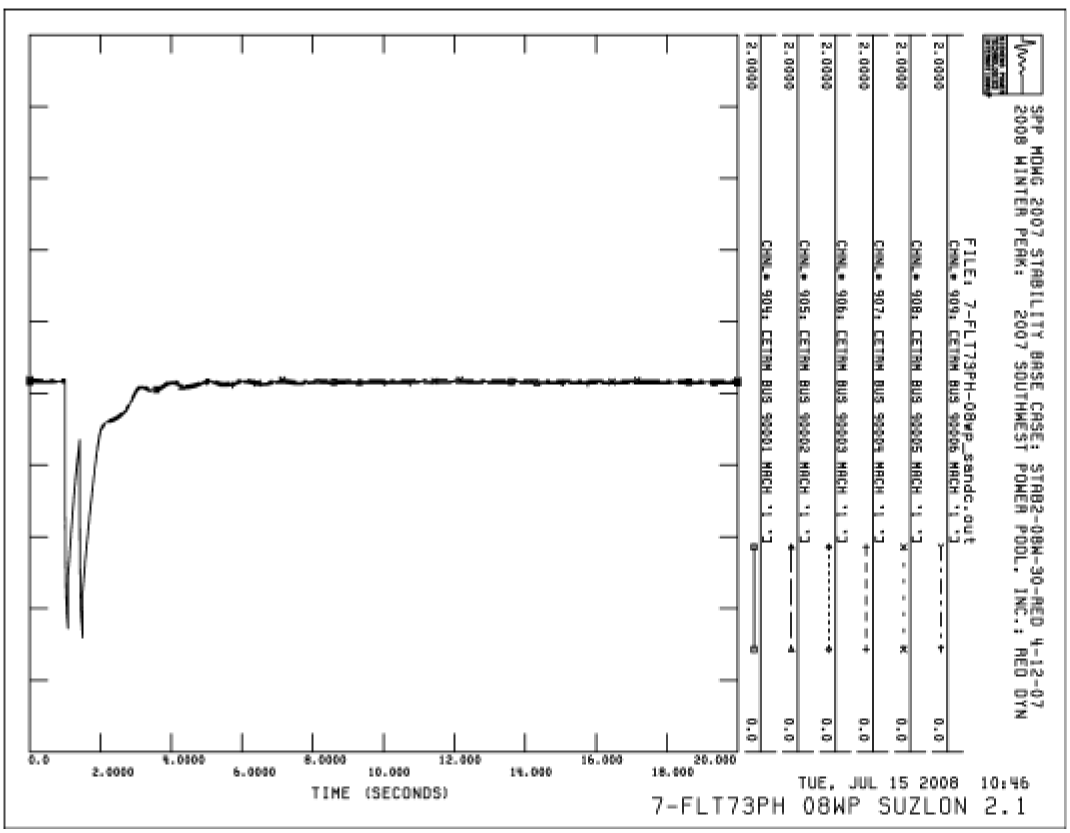

Figure 12: Suzlon terminal voltages for fault #7 with STATCOM (winter peak)

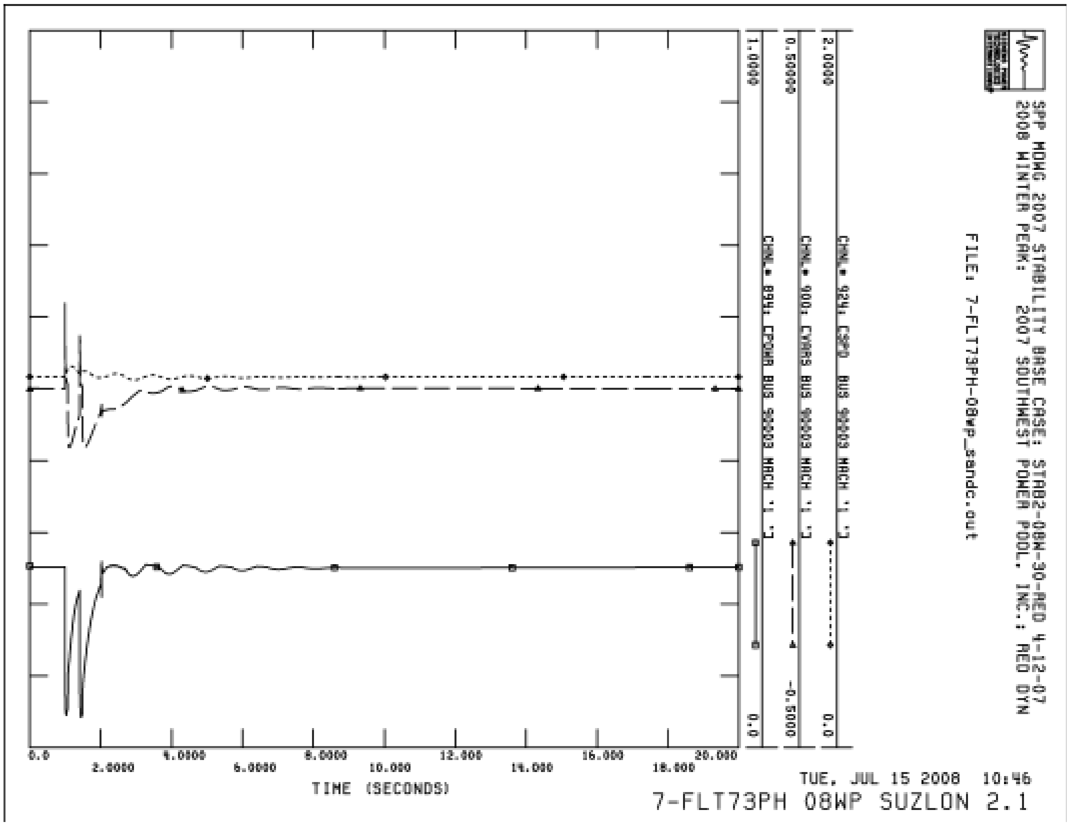

Figure 13: Suzlon performance (circuit 3) for fault #7 with STATCOM (winter peak)

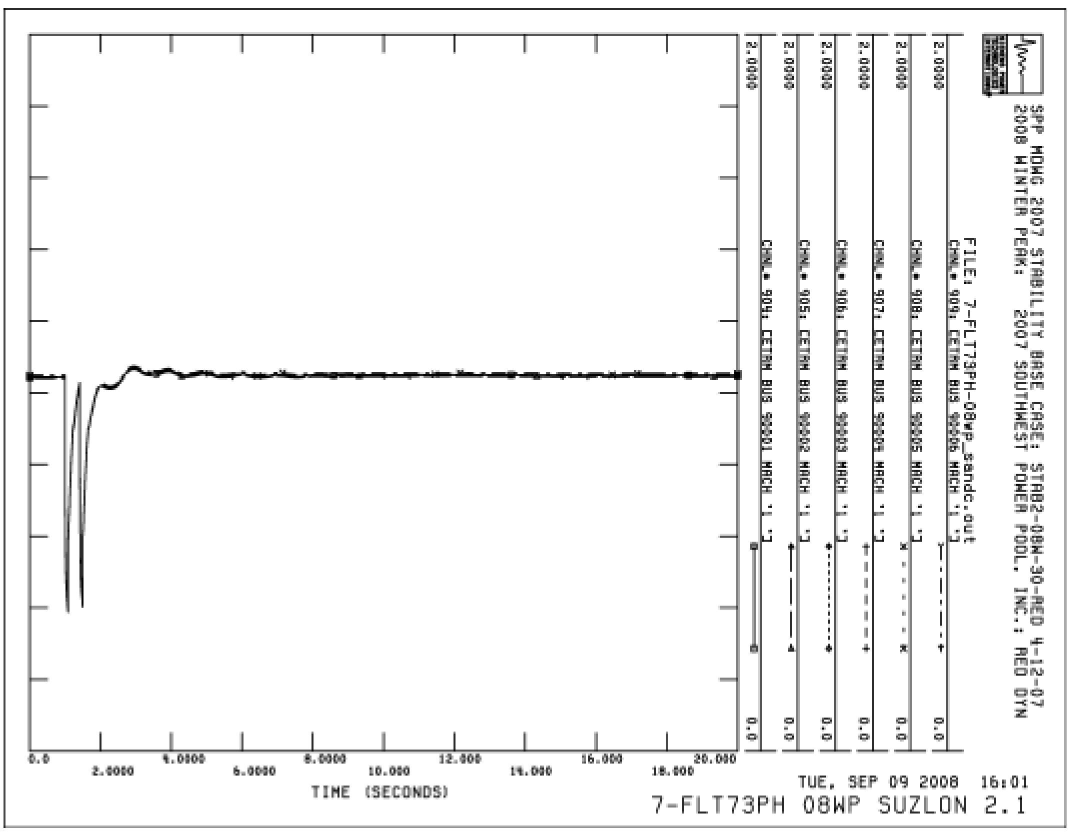

Figure 14: Suzlon terminal voltages for fault #7 post Hitchland project (winter peak)

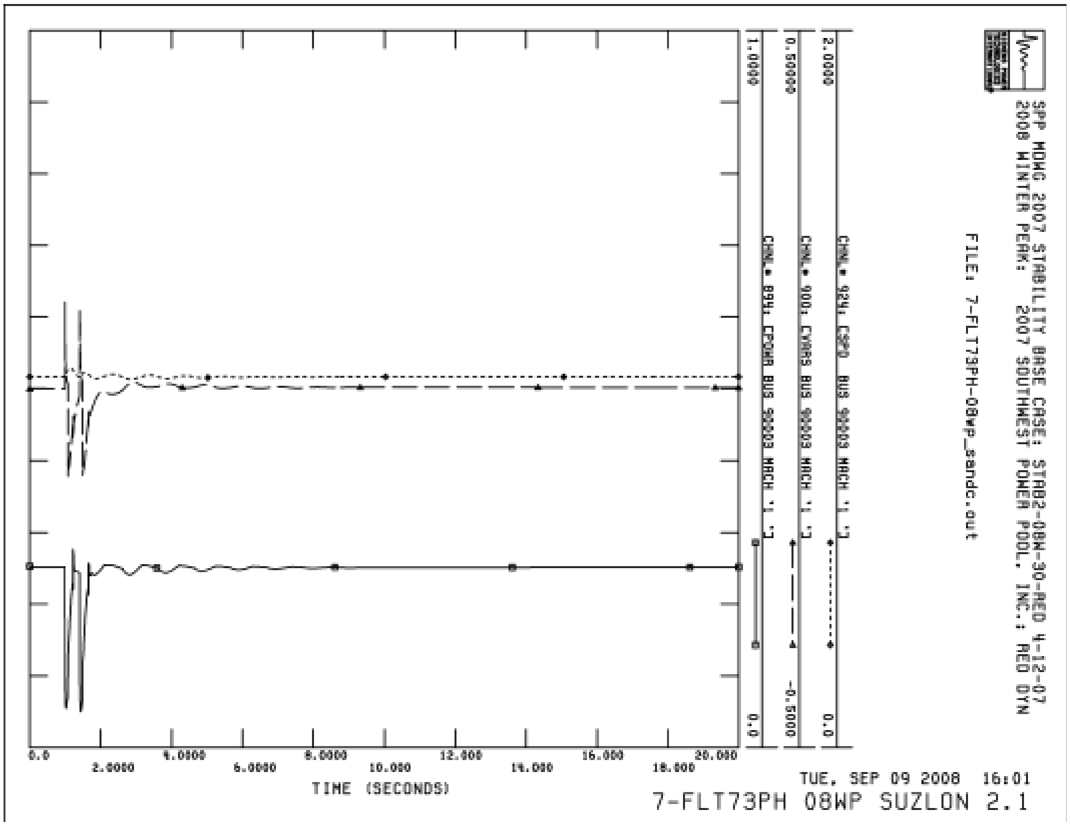

Figure 15: Suzlon performance (circuit 3) for fault #7 post Hitchland project (winter peak)

APPENDIX A

COLLECTOR IMPEDANCE CALCULATIONS

POWER FLOW MODEL PARAMETERS

115 KV, 397.5 ACSR, 6.5 miles, SC-ST, 24 feet equivalent spacing T-Line
(from Electrical Transmission and Distribution Reference Book)

	/mile							PU		
Length (ohms/miles)	R1 (ohms)	X1 (ohms)	Susceptance (micromho)	R1 (ohms)	X1 (ohms)	Susceptance (micromho)	Zbase (ohms)	R1	X1	Susceptance
6.5	0.259	0.8206	5.130836326	1.6835	5.3339	33.35043612	132.25	0.01273	0.040332	0.004410595

Main Transformer

Capacity
95 / 126 / 158 MVA

Voltage Ratio (Collector Side/Transmission System Side)
34.5 / 115 kV

Fixed Taps Available
Two 2.5% above and two 2.5% below

IMPEDANCE

Positive Z1 (on self-cooled kVA rating) 9 %

NoMansLand Wind Farm
Collector System Impedance Data
ALT. 1 : G.E. 1.5 MW Units
Preliminary Layout

Feeder 1 - GE 1.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No. of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB1	16	950	1000 kcmil	0.021	0.028	0.0760	28.651325	5.3504	7.0528
JB1	1.1	5	3250	4/0 AWG	0.341	0.156	0.1495	56.36017221	8.5313	3.9000
1.1	1.2	4	1000	1/0 AWG	0.210	0.152	0.0360	13.57168026	3.3600	2.4320
1.2	1.3	3	1000	1/0 AWG	0.210	0.152	0.0360	13.57168026	1.8900	1.3680
1.3	1.4	2	1000	1/0 AWG	0.210	0.152	0.0360	13.57168026	0.8400	0.6080
1.4	1.5	1	1000	1/0 AWG	0.210	0.152	0.0360	13.57168026	0.2100	0.1520
JB1	1.6	11	3250	500 kcmil	0.143	0.111	0.1983	74.73848923	17.3030	13.3705
1.6	1.7	10	1100	500 kcmil	0.048	0.037	0.0671	25.29610405	4.8400	3.7400
1.7	1.8	9	1100	500 kcmil	0.048	0.037	0.0671	25.29610405	3.9204	3.0294
1.8	1.9	8	1100	500 kcmil	0.048	0.037	0.0671	25.29610405	3.0976	2.3936
1.9	1.10	7	1100	4/0 AWG	0.116	0.053	0.0506	19.07575059	5.6595	2.5872
1.10	1.11	6	1100	4/0 AWG	0.116	0.053	0.0506	19.07575059	4.1580	1.9008
1.11	1.12	5	1750	4/0 AWG	0.184	0.084	0.0805	30.34778503	4.5938	2.1000
1.12	1.13	4	950	1/0 AWG	0.200	0.144	0.0342	12.89309625	3.1920	2.3104
1.13	1.14	3	950	1/0 AWG	0.200	0.144	0.0342	12.89309625	1.7955	1.2996
1.14	1.15	2	1900	1/0 AWG	0.399	0.289	0.0684	25.7861925	1.5960	1.1552
1.15	1.16	1	1000	1/0 AWG	0.210	0.152	0.0360	13.57168026	0.2100	0.1520
							Total =	423.5684	0.2756	0.1936
				Zbase =	11.9		Total in pu =	0.0050	0.0232	0.0163

Feeder 2 - GE 1.5 MW										
			Total	Conductor	Ohms				Equivalation	
		No. of	Length				Capacitance	Susceptance		
From	To	WTGs		Size	R1	X1	(micro F)	(umho)	R1eq	X1eq
Sub	JB2	17	2600	1000 kcmil	0.057	0.075	0.2080	78.41415263	16.5308	21.7906
JB2	2.1	8	1600	500 kcmil	0.070	0.054	0.0976	36.79433316	4.5056	3.4816
2.1	2.2	7	1100	4/0 AWG	0.116	0.053	0.0506	19.07575059	5.6595	2.5872
2.2	2.3	6	1100	4/0 AWG	0.116	0.053	0.0506	19.07575059	4.1580	1.9008
2.3	2.4	5	1100	4/0 AWG	0.116	0.053	0.0506	19.07575059	2.8875	1.3200
2.4	2.5	4	1100	1/0 AWG	0.231	0.167	0.0396	14.92884829	3.6960	2.6752
2.5	2.6	3	1100	1/0 AWG	0.231	0.167	0.0396	14.92884829	2.0790	1.5048
2.6	2.7	2	1100	1/0 AWG	0.231	0.167	0.0396	14.92884829	0.9240	0.6688
2.7	2.8	1	950	1/0 AWG	0.200	0.144	0.0342	12.89309625	0.1995	0.1444
JB2	2.9	9	3500	500 kcmil	0.154	0.119	0.2135	80.48760378	12.4740	9.6390
2.9	2.10	8	950	500 kcmil	0.042	0.032	0.0580	21.84663531	2.6752	2.0672
2.10	2.11	7	950	4/0 AWG	0.100	0.046	0.0437	16.47451188	4.8878	2.2344
2.11	2.12	6	950	4/0 AWG	0.100	0.046	0.0437	16.47451188	3.5910	1.6416
2.12	2.13	5	1200	4/0 AWG	0.126	0.058	0.0552	20.80990974	3.1500	1.4400
2.13	2.14	4	2000	1/0 AWG	0.420	0.304	0.0720	27.14336053	6.7200	4.8640
2.14	2.15	3	1600	1/0 AWG	0.336	0.243	0.0576	21.71468842	3.0240	2.1888
2.15	2.16	2	1300	1/0 AWG	0.273	0.198	0.0468	17.64318434	1.0920	0.7904
2.16	2.17	1	1500	1/0 AWG	0.315	0.228	0.0540	20.3575204	0.3150	0.2280
							Total =	473.0673	0.2719	0.2116
				Zbase =	11.9		Total in pu =	0.0056	0.0228	0.0178

Feeder 3 - GE 1.5 MW										
			Total	Conductor	Ohms				Equivalation	
		No. of	Length				Capacitance	Susceptance		
From	To	WTGs		Size	R1	X1	(micro F)	(umho)	R1eq	X1eq
Sub	3.1	17	16200	1000 kcmil	0.356	0.470	1.2960	488.5805	102.9996	135.7722
3.1	JB3	16	1850	1000 kcmil	0.041	0.054	0.1480	55.7947	10.4192	13.7344
JB3	3.2	10	100	500 kcmil	0.004	0.003	0.0061	2.2996	0.4400	0.3400
3.2	3.3	9	1100	500 kcmil	0.048	0.037	0.0671	25.2961	3.9204	3.0294
3.3	3.4	8	1000	500 kcmil	0.044	0.034	0.0610	22.9965	2.8160	2.1760
3.4	3.5	7	1100	4/0 AWG	0.116	0.053	0.0506	19.0758	5.6595	2.5872
3.5	3.6	6	1100	4/0 AWG	0.116	0.053	0.0506	19.0758	4.1580	1.9008
3.6	3.7	5	950	4/0 AWG	0.100	0.046	0.0437	16.4745	2.4938	1.1400
3.7	3.8	4	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	4.5360	3.2832
3.8	3.9	3	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	2.0790	1.5048
3.9	3.10	2	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	0.9240	0.6688
3.10	3.11	1	950	1/0 AWG	0.200	0.144	0.0342	12.8931	0.1995	0.1444
JB3	3.12	6	6500	4/0 AWG	0.683	0.312	0.2990	112.7203	24.5700	11.2320
3.12	3.13	5	1050	4/0 AWG	0.110	0.050	0.0483	18.2087	2.7563	1.2600
3.13	3.14	4	1050	1/0 AWG	0.221	0.160	0.0378	14.2503	3.5280	2.5536
3.14	3.15	3	1050	1/0 AWG	0.221	0.160	0.0378	14.2503	1.9845	1.4364
3.15	3.16	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
3.16	3.17	1	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	0.2310	0.1672
							Total =	901.3104	0.6046	0.6355
				Zbase =	11.9		Total in pu =	0.0107	0.0508	0.0534

Feeder 4 - GE 1.5 MW										
			Total	Conductor	Ohms				Equivalation	
		No. of	Length				Capacitance	Susceptance		
From	To	WTGs		Size	R1	X1	(micro F)	(umho)	R1eq	X1eq
Sub	4.1	17	24000	1000 kcmil	0.528	0.696	1.9200	723.8229	152.5920	201.1440
4.1	4.2	16	950	1000 kcmil	0.021	0.028	0.0760	28.6513	5.3504	7.0528
4.2	4.3	15	950	1000 kcmil	0.021	0.028	0.0760	28.6513	4.7025	6.1988
4.3	4.4	14	950	1000 kcmil	0.021	0.028	0.0760	28.6513	4.0964	5.3998
4.4	4.5	13	950	1000 kcmil	0.021	0.028	0.0760	28.6513	3.5321	4.6560
4.5	4.6	12	1950	1000 kcmil	0.043	0.057	0.1560	58.8106	6.1776	8.1432
4.6	4.7	11	950	500 kcmil	0.042	0.032	0.0580	21.8466	5.0578	3.9083
4.7	4.8	10	950	500 kcmil	0.042	0.032	0.0580	21.8466	4.1800	3.2300
4.8	4.9	9	950	500 kcmil	0.042	0.032	0.0580	21.8466	3.3858	2.6163
4.9	4.10	8	1000	500 kcmil	0.044	0.034	0.0610	22.9965	2.8160	2.1760
4.10	4.11	7	1100	4/0 AWG	0.116	0.053	0.0506	19.0758	5.6595	2.5872
4.11	4.12	6	1050	4/0 AWG	0.110	0.050	0.0483	18.2087	3.9690	1.8144
4.12	4.13	5	1050	4/0 AWG	0.110	0.050	0.0483	18.2087	2.7563	1.2600
4.13	4.14	4	1050	1/0 AWG	0.221	0.160	0.0378	14.2503	3.5280	2.5536
4.14	4.15	3	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	2.2680	1.6416
4.15	4.16	2	950	1/0 AWG	0.200	0.144	0.0342	12.8931	0.7980	0.5776
4.16	4.17	1	950	1/0 AWG	0.200	0.144	0.0342	12.8931	0.1995	0.1444
							Total =	1097.5908	0.7303	0.8827
				Zbase =	11.9		Total in pu =	0.0131	0.0614	0.0742

Feeder 5 - GE 1.5 MW										
			Total	Conductor	Ohms				Equivalation	
		No. of	Length				Capacitance	Susceptance		
From	To	WTGs		Size	R1	X1	(micro F)	(umho)	R1eq	X1eq
Sub	5.1	17	3800	1000 kcmil	0.084	0.110	0.3040	114.6053	24.1604	31.8478
5.1	5.2	16	1250	1000 kcmil	0.028	0.036	0.1000	37.6991	7.0400	9.2800
5.2	5.3	15	2300	1000 kcmil	0.051	0.067	0.1840	69.3664	11.3850	15.0075
5.3	5.4	14	1100	1000 kcmil	0.024	0.032	0.0880	33.1752	4.7432	6.2524
5.4	5.5	13	1350	1000 kcmil	0.030	0.039	0.1080	40.7150	5.0193	6.6164
5.5	5.6	12	1350	1000 kcmil	0.030	0.039	0.1080	40.7150	4.2768	5.6376
5.6	5.7	11	1100	500 kcmil	0.048	0.037	0.0671	25.2961	5.8564	4.5254
5.7	5.8	10	1000	500 kcmil	0.044	0.034	0.0610	22.9965	4.4000	3.4000
5.8	5.9	9	1900	500 kcmil	0.084	0.065	0.1159	43.6933	6.7716	5.2326
5.9	5.10	8	2000	500 kcmil	0.088	0.068	0.1220	45.9929	5.6320	4.3520
5.10	5.11	7	1100	4/0 AWG	0.116	0.053	0.0506	19.0758	5.6595	2.5872
5.11	5.12	6	3500	4/0 AWG	0.368	0.168	0.1610	60.6956	13.2300	6.0480
5.12	5.13	5	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	3.1500	1.4400
5.13	5.14	4	950	1/0 AWG	0.200	0.144	0.0342	12.8931	3.1920	2.3104
5.14	5.15	3	950	1/0 AWG	0.200	0.144	0.0342	12.8931	1.7955	1.2996
5.15	5.16	2	950	1/0 AWG	0.200	0.144	0.0342	12.8931	0.7980	0.5776
5.16	5.17	1	950	1/0 AWG	0.200	0.144	0.0342	12.8931	0.1995	0.1444
							Total =	626.4084	0.3713	0.3687
				Zbase =	11.9		Total in pu =	0.0075	0.0312	0.0310

Feeder 6 - GE 1.5 MW										
			Total	Conductor	Ohms				Equivalation	
		No. of	Length				Capacitance	Susceptance		
From	To	WTGs		Size	R1	X1	(micro F)	(umho)	R1eq	X1eq
Sub	6.1	16	3000	1000 kcmil	0.066	0.087	0.2400	90.4779	16.8960	22.2720
6.1	6.2	15	1200	1000 kcmil	0.026	0.035	0.0960	36.1911	5.9400	7.8300
6.2	6.3	14	7600	1000 kcmil	0.167	0.220	0.6080	229.2106	32.7712	43.1984
6.3	6.4	13	1700	1000 kcmil	0.037	0.049	0.1360	51.2708	6.3206	8.3317
6.4	6.5	12	950	1000 kcmil	0.021	0.028	0.0760	28.6513	3.0096	3.9672
6.5	6.6	11	950	500 kcmil	0.042	0.032	0.0580	21.8466	5.0578	3.9083
6.6	6.7	10	1600	500 kcmil	0.070	0.054	0.0976	36.7943	7.0400	5.4400
6.7	6.8	9	1100	500 kcmil	0.048	0.037	0.0671	25.2961	3.9204	3.0294
6.8	6.9	8	1100	500 kcmil	0.048	0.037	0.0671	25.2961	3.0976	2.3936
6.9	6.10	7	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	6.1740	2.8224
6.10	6.11	6	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	4.5360	2.0736
6.11	6.12	5	950	4/0 AWG	0.100	0.046	0.0437	16.4745	2.4938	1.1400
6.12	6.13	4	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	4.0320	2.9184
6.13	6.14	3	950	1/0 AWG	0.200	0.144	0.0342	12.8931	1.7955	1.2996
6.14	6.15	2	950	1/0 AWG	0.200	0.144	0.0342	12.8931	0.7980	0.5776
6.15	6.16	1	2300	1/0 AWG	0.483	0.350	0.0828	31.2149	0.4830	0.3496
							Total =	676.4163	0.4077	0.4357
				Zbase =	11.9		Total in pu =	0.0081	0.0343	0.0366

NoMansLand Wind Farm
Collector System Impedance Data
ALT. 2 : Suzlon 2.1 MW Units
Preliminary Layout
(See Drawings: Turbines Single-Line Diagram, Drawing No. BSLD-2 and Turbines Location Map, Drawing No. OK40197009)

Feeder 1 - Suzlon S88 2.1 MW												
			Total	Conductor	Ohms						Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	R0	X0	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB1	13	8350	1000 kcmil	0.184	0.242	0.735	0.058	0.6680	251.8301	31.0453	40.9234
JB1	1.1	8	100	500 kcmil	0.004	0.003	0.017	0.003	0.0061	2.2996	0.2816	0.2176
1.1	1.2	7	1650	500 kcmil	0.073	0.056	0.281	0.041	0.1007	37.9442	3.5574	2.7489
1.2	1.3	6	950	500 kcmil	0.042	0.032	0.162	0.024	0.0580	21.8466	1.5048	1.1628
1.3	1.4	5	1100	4/0 AWG	0.116	0.053	0.384	0.122	0.0506	19.0758	2.8875	1.3200
1.4	1.5	4	950	4/0 AWG	0.100	0.046	0.332	0.105	0.0437	16.4745	1.5960	0.7296
1.5	1.6	3	1100	1/0 AWG	0.231	0.167	0.579	0.282	0.0396	14.9288	2.0790	1.5048
1.6	1.7	2	1100	1/0 AWG	0.231	0.167	0.579	0.282	0.0396	14.9288	0.9240	0.6688
1.7	1.8	1	1250	1/0 AWG	0.263	0.190	0.658	0.320	0.0450	16.9646	0.2625	0.1900
JB1	1.9	5	7850	4/0 AWG	0.824	0.377	2.740	0.871	0.3611	136.1315	20.6063	9.4200
1.9	1.10	4	1250	4/0 AWG	0.131	0.060	0.436	0.139	0.0575	21.6770	2.1000	0.9600
1.10	1.11	3	1250	1/0 AWG	0.263	0.190	0.658	0.320	0.0450	16.9646	2.3625	1.7100
1.11	1.12	2	1600	1/0 AWG	0.336	0.243	0.842	0.410	0.0576	21.7147	1.3440	0.9728
1.12	1.13	1	1450	1/0 AWG	0.305	0.220	0.763	0.371	0.0522	19.6789	0.3045	0.2204
									Total =	612.4598	0.41926	0.37130
				Zbase =	11.9				**Total in pu =**	**0.007289802**	**0.03522**	**0.03119**

Feeder 2 - Suzlon S88 2.1 MW												
			Total	Conductor	Ohms						Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	R0	X0	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB2	13	3150	1000 kcmil	0.069	0.091	0.277	0.022	0.2520	95.0018	11.7117	15.4382
JB2	2.1	2	3800	1/0 AWG	0.798	0.578	1.999	0.973	0.1368	51.5724	3.1920	2.3104
2.1	2.2	1	1600	1/0 AWG	0.336	0.243	0.842	0.410	0.0576	21.7147	0.3360	0.2432
JB2	JB3	11	1650	1000 kcmil	0.036	0.048	0.145	0.012	0.1320	49.7628	4.3923	5.7899
JB3	2.3	3	1100	1/0 AWG	0.231	0.167	0.579	0.282	0.0396	14.9288	2.0790	1.5048
2.3	2.4	2	800	1/0 AWG	0.168	0.122	0.421	0.205	0.0288	10.8573	0.6720	0.4864
2.4	2.5	1	900	1/0 AWG	0.189	0.137	0.473	0.230	0.0324	12.2145	0.1890	0.1368
JB3	2.6	8	100	500 kcmil	0.004	0.003	0.017	0.003	0.0061	2.2996	0.2816	0.2176
2.6	2.7	7	1100	500 kcmil	0.048	0.037	0.187	0.028	0.0671	25.2961	2.3716	1.8326
2.7	2.8	6	1250	500 kcmil	0.055	0.043	0.213	0.031	0.0763	28.7456	1.9800	1.5300
2.8	2.9	5	950	4/0 AWG	0.100	0.046	0.332	0.105	0.0437	16.4745	2.4938	1.1400
2.9	2.10	4	1000	4/0 AWG	0.105	0.048	0.349	0.111	0.0460	17.3416	1.6800	0.7680
2.10	2.11	3	950	1/0 AWG	0.200	0.144	0.500	0.243	0.0342	12.8931	1.7955	1.2996
2.11	2.12	2	800	1/0 AWG	0.168	0.122	0.421	0.205	0.0288	10.8573	0.6720	0.4864
2.12	2.13	1	850	1/0 AWG	0.179	0.129	0.447	0.218	0.0306	11.5359	0.1785	0.1292
									Total =	381.4962	0.20133	0.19712
				Zbase =	11.9				**Total in pu =**	**0.004540758**	**0.01692**	**0.01656**

Feeder 3 - Suzlon S88 2.1 MW												
			Total	Conductor	Ohms						Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	R0	X0	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB4	12	7100	1000 kcmil	0.156	0.206	0.625	0.050	0.5680	214.1310	22.4928	29.6496
JB4	3.1	5	100	4/0 AWG	0.011	0.005	0.035	0.011	0.0046	1.7342	0.2625	0.1200
3.1	3.2	4	900	4/0 AWG	0.095	0.043	0.314	0.100	0.0414	15.6074	1.5120	0.6912
3.2	3.3	3	1650	1/0 AWG	0.347	0.251	0.868	0.422	0.0594	22.3933	3.1185	2.2572
3.3	3.4	2	850	1/0 AWG	0.179	0.129	0.447	0.218	0.0306	11.5359	0.7140	0.5168
3.4	3.5	1	1000	1/0 AWG	0.210	0.152	0.526	0.256	0.0360	13.5717	0.2100	0.1520
JB4	3.6	7	3200	500 kcmil	0.141	0.109	0.544	0.080	0.1952	73.5887	6.8992	5.3312
3.6	3.7	6	950	500 kcmil	0.042	0.032	0.162	0.024	0.0580	21.8466	1.5048	1.1628
3.7	3.8	5	950	4/0 AWG	0.100	0.046	0.332	0.105	0.0437	16.4745	2.4938	1.1400
3.8	3.9	4	1200	4/0 AWG	0.126	0.058	0.419	0.133	0.0552	20.8099	2.0160	0.9216
3.9	3.10	3	1100	1/0 AWG	0.231	0.167	0.579	0.282	0.0396	14.9288	2.0790	1.5048
3.10	3.11	2	1150	1/0 AWG	0.242	0.175	0.605	0.294	0.0414	15.6074	0.9660	0.6992
3.11	3.12	1	1650	1/0 AWG	0.347	0.251	0.868	0.422	0.0594	22.3933	0.3465	0.2508
									Total =	464.6227	0.30983	0.30831
				Zbase =	11.9				**Total in pu =**	**0.005530172**	**0.02603**	**0.02590**

Feeder 4 - Suzlon S88 2.1 MW												
			Total	Conductor	Ohms						Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	R0	X0	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB5	11	2750	1000 kcmil	0.061	0.080	0.242	0.019	0.2200	82.9380	7.3205	9.6498
JB5	4.1	4	100	4/0 AWG	0.011	0.005	0.035	0.011	0.0046	1.7342	0.1680	0.0768
4.1	4.2	3	2350	1/0 AWG	0.494	0.357	1.236	0.602	0.0846	31.8934	4.4415	3.2148
4.2	4.3	2	3200	1/0 AWG	0.672	0.486	1.683	0.819	0.1152	43.4294	2.6880	1.9456
4.3	4.4	1	1000	1/0 AWG	0.210	0.152	0.526	0.256	0.0360	13.5717	0.2100	0.1520
JB5	JB6	7	2350	500 kcmil	0.103	0.080	0.400	0.059	0.1434	54.0417	5.0666	3.9151
JB6	4.5	2	3600	1/0 AWG	0.756	0.547	1.894	0.922	0.1296	48.8580	3.0240	2.1888
4.5	4.6	1	2250	1/0 AWG	0.473	0.342	1.184	0.576	0.0810	30.5363	0.4725	0.3420
JB6	4.7	5	100	4/0 AWG	0.011	0.005	0.035	0.011	0.0046	1.7342	0.2625	0.1200
4.7	4.8	4	1250	4/0 AWG	0.131	0.060	0.436	0.139	0.0575	21.6770	2.1000	0.9600
4.8	4.9	3	1500	1/0 AWG	0.315	0.228	0.789	0.384	0.0540	20.3575	2.8350	2.0520
4.9	4.10	2	850	1/0 AWG	0.179	0.129	0.447	0.218	0.0306	11.5359	0.7140	0.5168
4.10	4.11	1	2200	1/0 AWG	0.462	0.334	1.157	0.563	0.0792	29.8577	0.4620	0.3344
									Total =	392.1650	0.24599	0.21048
				Zbase =	11.9				**Total in pu =**	**0.004667744**	**0.02067**	**0.01768**

Feeder 5 - Suzlon S88 2.1 MW												
			Total	Conductor	Ohms						Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	R0	X0	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB7	11	8000	1000 kcmil	0.176	0.232	0.704	0.056	0.6400	241.2743	21.2960	28.0720
JB7	5.1	2	2900	1/0 AWG	0.609	0.441	1.525	0.742	0.1044	39.3579	2.4360	1.7632
5.1	5.2	1	1650	1/0 AWG	0.347	0.251	0.868	0.422	0.0594	22.3933	0.3465	0.2508
JB7	5.3	9	7100	1000 kcmil	0.156	0.206	0.625	0.050	0.5680	214.1310	12.6522	16.6779
5.3	5.4	8	4900	500 kcmil	0.216	0.167	0.833	0.123	0.2989	112.6826	13.7984	10.6624
5.4	5.5	7	1400	500 kcmil	0.062	0.048	0.238	0.035	0.0854	32.1950	3.0184	2.3324
5.5	5.6	6	900	500 kcmil	0.040	0.031	0.153	0.023	0.0549	20.6968	1.4256	1.1016
5.6	5.7	5	1000	4/0 AWG	0.105	0.048	0.349	0.111	0.0460	17.3416	2.6250	1.2000
5.7	5.8	4	1900	4/0 AWG	0.200	0.091	0.663	0.211	0.0874	32.9490	3.1920	1.4592
5.8	5.9	3	850	1/0 AWG	0.179	0.129	0.447	0.218	0.0306	11.5359	1.6065	1.1628
5.9	5.10	2	850	1/0 AWG	0.179	0.129	0.447	0.218	0.0306	11.5359	0.7140	0.5168
5.10	5.11	1	1100	1/0 AWG	0.231	0.167	0.579	0.282	0.0396	14.9288	0.2310	0.1672
									Total =	771.0222	0.52348	0.54022
				Zbase =	11.9				**Total in pu =**	**0.009177092**	**0.04398**	**0.04539**

Feeder 6 - Suzlon S88 2.1 MW												
			Total	Conductor	Ohms						Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	R0	X0	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	6.1	11	28700	1000 kcmil	0.631	0.832	2.526	0.201	2.2960	865.5716	76.3994	100.7083
6.1	6.2	10	850	1000 kcmil	0.019	0.025	0.075	0.006	0.0680	25.6354	1.8700	2.4650
6.2	6.3	9	1100	1000 kcmil	0.024	0.032	0.097	0.008	0.0880	33.1752	1.9602	2.5839
6.3	6.4	8	850	500 kcmil	0.037	0.029	0.145	0.021	0.0519	19.5470	2.3936	1.8496
6.4	6.5	7	850	500 kcmil	0.037	0.029	0.145	0.021	0.0519	19.5470	1.8326	1.4161
6.5	6.6	6	1100	500 kcmil	0.048	0.037	0.187	0.028	0.0671	25.2961	1.7424	1.3464
6.6	6.7	5	1200	4/0 AWG	0.126	0.058	0.419	0.133	0.0552	20.8099	3.1500	1.4400
6.7	6.8	4	1200	4/0 AWG	0.126	0.058	0.419	0.133	0.0552	20.8099	2.0160	0.9216
6.8	6.9	3	1000	1/0 AWG	0.210	0.152	0.526	0.256	0.0360	13.5717	1.8900	1.3680
6.9	6.10	2	1000	1/0 AWG	0.210	0.152	0.526	0.256	0.0360	13.5717	0.8400	0.6080
6.10	6.11	1	950	1/0 AWG	0.200	0.144	0.500	0.243	0.0342	12.8931	0.1995	0.1444
									Total =	1070.4286	0.77929	0.94918
				Zbase =	11.9				**Total in pu =**	**0.012740776**	**0.06547**	**0.07975**

NoMansLand Wind Farm
Collector System Impedance Data
ALT. 3 : Mitsubishi 2.4 MW Units
Preliminary Layout
(See Drawings: Turbines Single-Line Diagram, Drawing No. BSLD-Mitsubishi and
Turbines Location Map, Drawing No. OK40197009-Mitsubishi)

Feeder 1 - Mitsubishi MWT-95 2.4 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB1	10	4500	1000 kcmil	0.099	0.131	0.3600	135.7168	9.9000	13.0500
JB1	1.1	8	850	1000 kcmil	0.019	0.025	0.0680	25.6354	1.1968	1.5776
1.1	1.2	7	1100	1000 kcmil	0.024	0.032	0.0880	33.1752	1.1858	1.5631
1.2	1.3	6	1100	500 kcmil	0.048	0.037	0.0671	25.2961	1.7424	1.3464
1.3	1.4	5	1100	500 kcmil	0.048	0.037	0.0671	25.2961	1.2100	0.9350
1.4	1.5	4	1150	4/0 AWG	0.121	0.055	0.0529	19.9428	1.9320	0.8832
1.5	1.6	3	1950	4/0 AWG	0.205	0.094	0.0897	33.8161	1.8428	0.8424
1.6	1.7	2	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	1.1340	0.8208
1.7	1.8	1	1250	1/0 AWG	0.263	0.190	0.0450	16.9646	0.2625	0.1900
JB1	1.9	2	850	1/0 AWG	0.179	0.129	0.0306	11.5359	0.7140	0.5168
1.9	1.10	1	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	0.2310	0.1672
							Total =	360.6297	0.21351	0.21725
				Zbase =	11.9025		**Total in pu =**	**0.004292395**	**0.01794**	**0.01825**

Feeder 2 - Mitsubishi MWT-95 2.4 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB2	10	9600	1000 kcmil	0.211	0.278	0.7680	289.5292	21.1200	27.8400
JB2	2.1	6	700	500 kcmil	0.031	0.024	0.0427	16.0975	1.1088	0.8568
2.1	2.2	5	1900	500 kcmil	0.084	0.065	0.1159	43.6933	2.0900	1.6150
2.2	2.3	4	1100	4/0 AWG	0.116	0.053	0.0506	19.0758	1.8480	0.8448
2.3	2.4	3	1500	4/0 AWG	0.158	0.072	0.0690	26.0124	1.4175	0.6480
2.4	2.5	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
2.5	2.6	1	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	0.2520	0.1824
JB2	2.7	4	5400	4/0 AWG	0.567	0.259	0.2484	93.6446	9.0720	4.1472
2.7	2.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
2.8	2.9	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
2.9	2.10	1	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	0.2520	0.1824
							Total =	574.0067	0.40310	0.38294
				Zbase =	11.9025		**Total in pu =**	**0.006832114**	**0.03387**	**0.03217**

Feeder 3 - Mitsubishi MWT-95 2.4 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB3	10	5200	1000 kcmil	0.114	0.151	0.4160	156.8283	11.4400	15.0800
JB3	3.1	2	2150	1/0 AWG	0.452	0.327	0.0774	29.1791	1.8060	1.3072
3.1	3.2	1	1550	1/0 AWG	0.326	0.236	0.0558	21.0361	0.3255	0.2356
JB3	3.3	5	13500	500 kcmil	0.594	0.459	0.8235	310.4522	14.8500	11.4750
3.3	3.4	4	1300	4/0 AWG	0.137	0.062	0.0598	22.5441	2.1840	0.9984
3.4	3.5	3	1450	4/0 AWG	0.152	0.070	0.0667	25.1453	1.3703	0.6264
3.5	3.6	2	1700	1/0 AWG	0.357	0.258	0.0612	23.0719	1.4280	1.0336
3.6	3.7	1	2000	1/0 AWG	0.420	0.304	0.0720	27.1434	0.4200	0.3040
JB3	3.8	3	5700	4/0 AWG	0.599	0.274	0.2622	98.8471	5.3865	2.4624
3.8	3.9	2	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	1.1340	0.8208
3.9	3.10	1	1600	1/0 AWG	0.336	0.243	0.0576	21.7147	0.3360	0.2432
							Total =	754.2838	0.40680	0.34343
				Zbase =	11.9025		**Total in pu =**	**0.008977863**	**0.03418**	**0.02885**

Feeder 4 - Mitsubishi MWT-95 2.4 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	4.1	10	30000	1000 kcmil	0.660	0.870	2.4000	904.7787	66.0000	87.0000
4.1	4.2	9	1350	1000 kcmil	0.030	0.039	0.1080	40.7150	2.4057	3.1712
4.2	4.3	8	1200	1000 kcmil	0.026	0.035	0.0960	36.1911	1.6896	2.2272
4.3	4.4	7	1200	1000 kcmil	0.026	0.035	0.0960	36.1911	1.2936	1.7052
4.4	4.5	6	1200	500 kcmil	0.053	0.041	0.0732	27.5957	1.9008	1.4688
4.5	4.6	5	1200	500 kcmil	0.053	0.041	0.0732	27.5957	1.3200	1.0200
4.6	4.7	4	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	2.0160	0.9216
4.7	4.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
4.8	4.9	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
4.9	4.10	1	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	0.2835	0.2052
							Total =	1149.2951	0.79051	0.98967
				Zbase =	11.9025		**Total in pu =**	**0.013679485**	**0.06642**	**0.08315**

Feeder 5 - Mitsubishi MWT-95 2.4 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB4	10	9200	1000 kcmil	0.202	0.267	0.7360	277.4655	20.2400	26.6800
JB4	5.1	1	2850	1/0 AWG	0.599	0.433	0.1026	38.6793	0.5985	0.4332
JB4	5.2	9	8400	1000 kcmil	0.185	0.244	0.6720	253.3380	14.9688	19.7316
5.2	5.3	8	5150	1000 kcmil	0.113	0.149	0.4120	155.3203	7.2512	9.5584
5.3	5.4	7	1350	1000 kcmil	0.030	0.039	0.1080	40.7150	1.4553	1.9184
5.4	5.5	6	1200	500 kcmil	0.053	0.041	0.0732	27.5957	1.9008	1.4688
5.5	5.6	5	1100	500 kcmil	0.048	0.037	0.0671	25.2961	1.2100	0.9350
5.6	5.7	4	1600	4/0 AWG	0.168	0.077	0.0736	27.7465	2.6880	1.2288
5.7	5.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
5.8	5.9	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
5.9	5.10	1	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	0.2520	0.1824
							Total =	899.5385	0.52707	0.63385
				Zbase =	11.9025		**Total in pu =**	**0.010706757**	**0.04428**	**0.05325**

Feeder 6 - Mitsubishi MWT-95 2.4 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB5	10	3000	1000 kcmil	0.066	0.087	0.2400	90.4779	6.6000	8.7000
JB5	6.1	2	200	1/0 AWG	0.042	0.030	0.0072	2.7143	0.1680	0.1216
6.1	6.2	1	3500	1/0 AWG	0.735	0.532	0.1260	47.5009	0.7350	0.5320
JB5	6.3	8	2700	1000 kcmil	0.059	0.078	0.2160	81.4301	3.8016	5.0112
6.3	6.4	7	4850	1000 kcmil	0.107	0.141	0.3880	146.2726	5.2283	6.8919
6.4	6.5	6	4350	500 kcmil	0.191	0.148	0.2654	100.0346	6.8904	5.3244
6.5	6.6	5	2600	500 kcmil	0.114	0.088	0.1586	59.7908	2.8600	2.2100
6.6	6.7	4	3100	4/0 AWG	0.326	0.149	0.1426	53.7589	5.2080	2.3808
6.7	6.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
6.8	6.9	2	2150	1/0 AWG	0.452	0.327	0.0774	29.1791	1.8060	1.3072
6.9	6.10	1	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	0.2310	0.1672
							Total =	646.8979	0.34662	0.33165
				Zbase =	11.9025		**Total in pu =**	**0.007699702**	**0.02912**	**0.02786**

NoMansLand Wind Farm
Collector System Impedance Data
ALT. 4 : Clipper 2.5 MW Units
Preliminary Layout
(See Drawings: Turbines Single-Line Diagram, Drawing No. BSLD-Clipper and Turbines Location Map, Drawing No. OK40197009-Clipper)

Feeder 1 – Clipper C93 2.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB1	10	4500	1000 kcmil	0.099	0.131	0.3600	135.7168	9.9000	13.0500
JB1	1.1	8	850	1000 kcmil	0.019	0.025	0.0680	25.6354	1.1968	1.5776
1.1	1.2	7	1100	1000 kcmil	0.024	0.032	0.0880	33.1752	1.1858	1.5631
1.2	1.3	6	1100	500 kcmil	0.048	0.037	0.0671	25.2961	1.7424	1.3464
1.3	1.4	5	1100	500 kcmil	0.048	0.037	0.0671	25.2961	1.2100	0.9350
1.4	1.5	4	1150	4/0 AWG	0.121	0.055	0.0529	19.9428	1.9320	0.8832
1.5	1.6	3	1950	4/0 AWG	0.205	0.094	0.0897	33.8161	1.8428	0.8424
1.6	1.7	2	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	1.1340	0.8208
1.7	1.8	1	1250	1/0 AWG	0.263	0.190	0.0450	16.9646	0.2625	0.1900
JB1	1.9	2	850	1/0 AWG	0.179	0.129	0.0306	11.5359	0.7140	0.5168
1.9	1.10	1	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	0.2310	0.1672
							Total =	360.6297	0.21351	0.21725
				Zbase =	11.9025		**Total in pu =**	**0.004292395**	**0.01794**	**0.01825**

S&C ELECTRIC COMPANY

Feeder 2 – Clipper C93 2.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB2	10	9600	1000 kcmil	0.211	0.278	0.7680	289.5292	21.1200	27.8400
JB2	2.1	6	700	500 kcmil	0.031	0.024	0.0427	16.0975	1.1088	0.8568
2.1	2.2	5	1900	500 kcmil	0.084	0.065	0.1159	43.6933	2.0900	1.6150
2.2	2.3	4	1100	4/0 AWG	0.116	0.053	0.0506	19.0758	1.8480	0.8448
2.3	2.4	3	1500	4/0 AWG	0.158	0.072	0.0690	26.0124	1.4175	0.6480
2.4	2.5	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
2.5	2.6	1	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	0.2520	0.1824
JB2	2.7	4	5400	4/0 AWG	0.567	0.259	0.2484	93.6446	9.0720	4.1472
2.7	2.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
2.8	2.9	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
2.9	2.10	1	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	0.2520	0.1824
							Total =	574.0067	0.40310	0.38294
				Zbase =	11.9025		**Total in pu =**	**0.006832114**	**0.03387**	**0.03217**

Feeder 3 – Clipper C93 2.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB3	10	5200	1000 kcmil	0.114	0.151	0.4160	156.8283	11.4400	15.0800
JB3	3.1	2	2150	1/0 AWG	0.452	0.327	0.0774	29.1791	1.8060	1.3072
3.1	3.2	1	1550	1/0 AWG	0.326	0.236	0.0558	21.0361	0.3255	0.2356
JB3	3.3	5	13500	500 kcmil	0.594	0.459	0.8235	310.4522	14.8500	11.4750
3.3	3.4	4	1300	4/0 AWG	0.137	0.062	0.0598	22.5441	2.1840	0.9984
3.4	3.5	3	1450	4/0 AWG	0.152	0.070	0.0667	25.1453	1.3703	0.6264
3.5	3.6	2	1700	1/0 AWG	0.357	0.258	0.0612	23.0719	1.4280	1.0336
3.6	3.7	1	2000	1/0 AWG	0.420	0.304	0.0720	27.1434	0.4200	0.3040
JB3	3.8	3	5700	4/0 AWG	0.599	0.274	0.2622	98.8471	5.3865	2.4624
3.8	3.9	2	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	1.1340	0.8208
3.9	3.10	1	1600	1/0 AWG	0.336	0.243	0.0576	21.7147	0.3360	0.2432
							Total =	754.2838	0.40680	0.34343
				Zbase =	11.9025		**Total in pu =**	**0.008977863**	**0.03418**	**0.02885**

Feeder 4 – Clipper C93 2.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	4.1	10	30000	1000 kcmil	0.660	0.870	2.4000	904.7787	66.0000	87.0000
4.1	4.2	9	1350	1000 kcmil	0.030	0.039	0.1080	40.7150	2.4057	3.1712
4.2	4.3	8	1200	1000 kcmil	0.026	0.035	0.0960	36.1911	1.6896	2.2272
4.3	4.4	7	1200	1000 kcmil	0.026	0.035	0.0960	36.1911	1.2936	1.7052
4.4	4.5	6	1200	500 kcmil	0.053	0.041	0.0732	27.5957	1.9008	1.4688
4.5	4.6	5	1200	500 kcmil	0.053	0.041	0.0732	27.5957	1.3200	1.0200
4.6	4.7	4	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	2.0160	0.9216
4.7	4.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
4.8	4.9	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
4.9	4.10	1	1350	1/0 AWG	0.284	0.205	0.0486	18.3218	0.2835	0.2052
							Total =	1149.2951	0.79051	0.98967
				Zbase =	11.9025		**Total in pu =**	**0.013679485**	**0.06642**	**0.08315**

Feeder 5 – Clipper C93 2.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB4	10	9200	1000 kcmil	0.202	0.267	0.7360	277.4655	20.2400	26.6800
JB4	5.1	1	2850	1/0 AWG	0.599	0.433	0.1026	38.6793	0.5985	0.4332
JB4	5.2	9	8400	1000 kcmil	0.185	0.244	0.6720	253.3380	14.9688	19.7316
5.2	5.3	8	5150	1000 kcmil	0.113	0.149	0.4120	155.3203	7.2512	9.5584
5.3	5.4	7	1350	1000 kcmil	0.030	0.039	0.1080	40.7150	1.4553	1.9184
5.4	5.5	6	1200	500 kcmil	0.053	0.041	0.0732	27.5957	1.9008	1.4688
5.5	5.6	5	1100	500 kcmil	0.048	0.037	0.0671	25.2961	1.2100	0.9350
5.6	5.7	4	1600	4/0 AWG	0.168	0.077	0.0736	27.7465	2.6880	1.2288
5.7	5.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
5.8	5.9	2	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	1.0080	0.7296
5.9	5.10	1	1200	1/0 AWG	0.252	0.182	0.0432	16.2860	0.2520	0.1824
							Total =	899.5385	0.52707	0.63385
				Zbase =	11.9025		**Total in pu =**	**0.010706757**	**0.04428**	**0.05325**

Feeder 6 – Clipper C93 2.5 MW										
			Total	Conductor	Ohms				Equivalation	
From	To	No of WTGs	Length	Size	R1	X1	Capacitance (micro F)	Susceptance (umho)	R1eq	X1eq
Sub	JB5	10	3000	1000 kcmil	0.066	0.087	0.2400	90.4779	6.6000	8.7000
JB5	6.1	2	200	1/0 AWG	0.042	0.030	0.0072	2.7143	0.1680	0.1216
6.1	6.2	1	3500	1/0 AWG	0.735	0.532	0.1260	47.5009	0.7350	0.5320
JB5	6.3	8	2700	1000 kcmil	0.059	0.078	0.2160	81.4301	3.8016	5.0112
6.3	6.4	7	4850	1000 kcmil	0.107	0.141	0.3880	146.2726	5.2283	6.8919
6.4	6.5	6	4350	500 kcmil	0.191	0.148	0.2654	100.0346	6.8904	5.3244
6.5	6.6	5	2600	500 kcmil	0.114	0.088	0.1586	59.7908	2.8600	2.2100
6.6	6.7	4	3100	4/0 AWG	0.326	0.149	0.1426	53.7589	5.2080	2.3808
6.7	6.8	3	1200	4/0 AWG	0.126	0.058	0.0552	20.8099	1.1340	0.5184
6.8	6.9	2	2150	1/0 AWG	0.452	0.327	0.0774	29.1791	1.8060	1.3072
6.9	6.10	1	1100	1/0 AWG	0.231	0.167	0.0396	14.9288	0.2310	0.1672
							Total =	646.8979	0.34662	0.33165
				Zbase =	11.9025		**Total in pu =**	**0.007699702**	**0.02912**	**0.02786**

GEN-2002-006 load flow parameters with GE 1.5 MW turbines

For: Feeder 1 Feeder 6	Parameters
16 GE 1.5 MW wind turbine generators at 0.575 kV	16 * 1.5 MW = 24 MW 16 * 1.667 MVA = 26.67 MVA Power factor at 0.575 kV bus: 0.98 lagging
16 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	16 * 1.85 MVA = 29.6 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 29.6 MVA base

For: Feeder 2 Feeder 3 Feeder 4 Feeder 5	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: 0.98 lagging
17 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	17 * 1.85 MVA = 31.45 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 31.45 MVA base

GEN-2002-006 load flow parameters with Suzlon S88 2.1 MW turbines

For: Feeder 1 Feeder 2	Parameters
13 Suzlon 2.1 MW wind turbine generators at 0.6 kV	13 * 2.10 MW = 27.3 MW 13 * 2.28 MVA = 29.64 MVA
13 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	13 * 2.5 MVA = 32.5 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 32.5 MVA base

For: Feeder 3	Parameters
12 Suzlon 2.1 MW wind turbine generators at 0.6 kV	12 * 2.10 MW = 25.2 MW 12 * 2.28 MVA = 27.36 MVA
12 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	12 * 2.5 MVA = 30 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 30 MVA base

For: Feeder 4 Feeder 5 Feeder 6	Parameters
11 Suzlon 2.1 MW wind turbine generators at 0.6 kV	11 * 2.10 MW = 23.1 MW 11 * 2.28 MVA = 25.08 MVA
11 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	11 * 2.5 MVA = 27.5 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 27.5 MVA base

GEN-2002-006 load flow parameters with Mitsubishi MWT-95 2.4 MW turbines

For: Feeder 1 Feeder 2 Feeder 3 Feeder 4 Feeder 5 Feeder 6	Parameters
10 Mitsubishi MWT-95 2.4 MW wind turbine generators at 0.69 kV	10 * 2.40 MW = 24 MW 10 * 2.52 MVA = 25.2 MVA
10 Permanently connected shunt capacitors at 0.69 kV	10 * 0.11 MVAR = 1.1 MVAR
10 Pad mounted wind turbine generator transformers 0.69 / 34.5 kV transformers	10 * 2.7 MVA = 27 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 27 MVA base

GEN-2002-006 load flow parameters with Clipper C93 2.5 MW turbines

For: Feeder 1 Feeder 2 Feeder 3 Feeder 4 Feeder 5 Feeder 6	Parameters
10 Clipper C93 2.5 MW wind turbine generators at 0.69 kV	10 * 2.5 MW = 24 MW 10 * 2.63 MVA = 26.32 MVA
10 Pad mounted wind turbine generator transformers 0.69 / 34.5 kV transformers	10 * 2.7 MVA = 27 MVA X/R = 7.25 %IZ = 4.9 Z1 = 0.01450 + 0.07104j p.u. on 27 MVA base

APPENDIX B

DYNAMIC STABILITY PLOTS – POST PROJECT

GE 1.5 MW

WINTER PEAK 2008

Flat run
and
Fault contingencies #1 thru #14

SUMMER PEAK 2012

Flat run
and
Fault contingencies #1 thru #14

APPENDIX C

DYNAMIC STABILITY PLOTS – POST PROJECT

SUZLON S88 2.1 MW

WITHOUT STATCOM

WINTER PEAK 2008

Flat run
and
Fault contingencies #1 thru #14

SUMMER PEAK 2012

Flat run
and
Fault contingencies #1 thru #14

APPENDIX D

DYNAMIC STABILITY PLOTS – POST PROJECT

MITSUBISHI S88 2.4 MW

WINTER PEAK 2008

Flat run
and
Fault contingencies #1 thru #14

SUMMER PEAK 2012

Flat run
and
Fault contingencies #1 thru #14

APPENDIX E

DYNAMIC STABILITY PLOTS – POST PROJECT

CLIPPER C93 2.5 MW

WINTER PEAK 2008

Flat run
and
Fault contingencies #1 thru #14

SUMMER PEAK 2012

Flat run
and
Fault contingencies #1 thru #14

APPENDIX F

DYNAMIC STABILITY PLOTS – POST PROJECT

SUZLON S88 2.1 MW

WITH STATCOM

WINTER PEAK 2008

Fault contingencies #7 and #8

SUMMER PEAK 2012

Fault contingencies #7 and #8

APPENDIX G

DYNAMIC STABILITY PLOTS – POST PROJECT

SUZLON S88 2.1 MW

POST HITCHLAND PROJECT

WINTER PEAK 2008

Fault contingencies #7 and #8

SUMMER PEAK 2012

Fault contingencies #7 and #8