Southwest Power Pool

System Impact Study for Generation Interconnection Request

GEN-2003-005

SPP Tariff Studies

(#GEN-2003-005)

September 2008

SUMMARY

S&C Electric Company performed the following re-Study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request GEN-2003-005. The request for interconnection was placed with SPP in accordance with SPP's Open Access Transmission Tariff, which covers new generation interconnections on SPP's transmission system.

Pursuant to the tariff, S&C was asked to perform a detailed stability analysis of the generation interconnection request to satisfy the Impact Study Agreement executed by the requesting customer and SPP. This re-study was conducted due to request by the Customer to change the manufacturer of the wind turbines at the wind farm from Vestes V80 wind turbines to Suzlon S88 wind turbines. .

Interconnection Customer Interconnection Facilities

The Impact Study has determined that a 34.5kV, +/- 9 MVA continuous (24 MVA short term rating) STATCOM device is required for interconnection to meet FERC Order #661A requirements for low voltage ride through.

Transmission Owner Interconnection Facilities and Network Upgrades

A Facility Study for this Generation Interconnection request was completed in February, 2006. An Interconnection Agreement was executed in 2006 and was subsequently placed in suspension. If this Interconnection Agreement is brought out of suspension, the Interconnection Facility costs will need to be updated by the Transmission Owner by means of a new Facility Study.

Final Report

For

Southwest Power Pool

From

S&C Electric Company

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST
GEN-2003-005

S&C Project No. 3189

September 25, 2008

S&C Electric Company

S&C Electric Company, Chicago, IL 60626-3997, Phone: (773) 338-1000

Power Systems Services Division Fax: (773) 338-4254

TABLE OF CONTENTS

Report Revision History:

Date of Report	Issue	Comments
September 19, 2008	Rev. A	Draft for review and comments
September 25, 2008	Rev. 0	Final version

Report prepared by:

George Tsai
Project Engineer

EXECUTIVE SUMMARY

This system impact study was performed in response to a generation interconnection study request through the Southwest Power Pool Tariff for a 100 MW wind farm in Grady County, Oklahoma. The proposed wind project would consist of 47 Suzlon S88 2.1 MW wind turbine generators and interconnect into a new substation to be built along the 138 kV Anadarko to Paradise transmission line owned by the Western Farmers Electric Cooperative (WFEC). The objective of this study has been to determine the impact of the interconnection at 100% output power on the stability of nearby areas and prior queued projects for winter and summer peak 2008 seasonal cases and identify reactive power compensation requirements in order to successfully integrate the project into the transmission system.

Need has been identified for mechanically switched shunt capacitors (MSSC), STATCOM or both at 34.5 kV or/and 138 kV for steady-state reactive power support. Switched capacitor banks, which are supplied with each Suzlon wind turbine generator, provide some reactive power support, yet still insufficient to compensate for voltage transformation and collector cable losses. Study results indicate that voltages at the project and Paradise would collapse when the 138 kV line from the Wind Farm Point of Interconnection (POI) to Anadarko is outaged. This does not occur prior to the project and is clearly the result of the interconnection. Furthermore, QV analysis performed at the POI shows that voltages have to be 1.00 pu or above for the summer case and 1.01 pu or above for the winter case for stable system operation. Essentially, the project needs to supply sufficient reactive power to meet unity power factor at the POI when the Anadarko – Wind Farm POI 138 kV line is offline. This power factor requirement can be met through the use of switched capacitor banks, STATCOM, or a combination of the two.

Three-phase and single-phase-to-ground faults were studied at locations specified by SPP. Suzlon wind turbine generators will disconnect on low voltage relay actuation for faults near the project on the POI – Anadarko 138 kV line. High-speed reactive power support is needed to help the turbines ride thru the fault and satisfy the FERC Order 661A provisions on low-voltage ride through (LVRT). Either a STATCOM or SVC is required to keep wind turbines connected and maintain system stability.

Sensitivity analysis indicates that a +/- 9 MVA STATCOM with 2-second short-time rating of +/-23.76 MVA (2.64 pu) located at the 34.5 kV collector bus will provide the high-speed and smooth reactive supply required to keep the project connected and retain system stability. The performance of the STATCOM will depend on the specific device; therefore, a separate sizing study using device specific dynamic models must demonstrate that the proposed device will keep the project connected and retain system stability for all fault contingencies.

The +/- 9 MVAR STATCOM has a continuous range that can be used for steady-state reactive power support, but it is still not sufficient to meet the unity power factor requirement at the POI when the Anadarko – Wind Farm POI 138 kV line is outaged. This will require a 3.6 MVAR mechanically switched capacitor bank located at either the 138 kV POI or at the 34.5 kV collector bus.

1. INTRODUCTION

This system impact study was performed in response to a generation interconnection study request through the Southwest Power Pool Tariff for a 100 MW wind farm in Grady County, Oklahoma. The proposed wind project would consist of 47 Suzlon S88 2.1 MW wind turbine generators to be interconnected into a new substation to be built along the 138 kV Anadarko to Paradise transmission line owned by the Western Farmers Electric Cooperative (WFEC). The objective of this study is to determine the impact of the interconnection at 100% output power on the stability of nearby areas and prior queued projects for winter and summer seasonal peak 2008 cases and identify any reactive power compensation requirements in order to successfully integrate the project into the transmission system.

2. LOAD FLOW STUDY AND RESULTS

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

Table 1: GEN-2003-005 Model Parameters

Circuit 1	Parameters
11 Suzlon S88 2.1 MW wind turbine generators at 0.6 kV	11 * 2.10 MW = 23.10 MW 11 * 2.28 MVA = 25.11 MVA pf at 0.6 kV bus: 0.9995 lead (capacitive)
11 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	11 * 2.5 MVA = 27.5 MVA X/R = 10, %IZ = 5.75 Z1 = 0.00572 + 0.05721j p.u. on 27.5 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.06418 + 0.06789j p.u. on 100 MVA base B1 = 0.009703142 p.u. on 100 MVA base

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

Circuit 2	Parameters
11 Suzlon S88 2.1 MW wind turbine generators at 0.6 kV	11 * 2.10 MW = 23.10 MW 11 * 2.28 MVA = 25.11 MVA pf at 0.6 kV bus: 0.9995 lead (capacitive)
11 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	11 * 2.5 MVA = 27.5 MVA X/R = 10, %IZ = 5.75 Z1 = 0.00572 + 0.05721j p.u. on 27.5 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.04007 + 0.03448j p.u. on 100 MVA base B1 = 0.006189499 p.u. on 100 MVA base

Circuit 3	Parameters
13 Suzlon S88 2.1 MW wind turbine generators at 0.6 kV	13 * 2.10 MW = 27.3 MW 13 * 2.28 MVA = 29.64 MVA Pf at 0.6 kV bus: 0.9995 lead (capacitive)
13 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	13 * 2.5 MVA = 32.5 MVA X/R = 10, %IZ = 5.75 Z1 = 0.00572 + 0.05721j p.u. on 32.5 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.01001 + 0.01193j p.u. on 100 MVA base B1 = 0.003630503 p.u. on 100 MVA base

Circuit 4	Parameters
13 Suzlon S88 2.1 MW wind turbine generators at 0.6 kV	13 * 2.10 MW = 27.3 MW 13 * 2.28 MVA = 29.64 MVA Pf at 0.6 kV bus: 0.9995 lead (capacitive)
13 Pad mounted wind turbine generator transformers 0.6 / 34.5 kV transformers	13 * 2.5 MVA = 32.5 MVA X/R = 10, %IZ = 5.75 Z1 = 0.00572 + 0.05721j p.u. on 32.5 MVA base Fixed no load tap = flat
Equivalent collector circuit impedance	Z1 = 0.03751 + 0.04210j p.u. on 100 MVA base B1 = 0.007546693 p.u. on 100 MVA base

Substation	Parameters
34.5 / 138 kV main transformer	MVA ratings = 69/92/115 MVA X/R = 30 (typical) %IZ = 9 on self-cooled MVA rating Z1 = 0.00300+ 0.08995j p.u. on 69 MVA base Fixed HV tap setting = 2.5% above (141.45 kV)

2.1 Modeling of 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. Each wind turbine is set at 0.9995 leading power factor to take full advantage of their steady-state reactive output capability.

2.2 Power Factor Requirements at the POI

The project can be successfully integrated into the transmission system provided the project can hold the voltage at the POI to an adequate level for outage/fault contingencies listed in Table 2. Table 3 lists the voltages at the POI for each contingency in Table 2 for the Pre-Project case. Table 4 lists the voltages at the POI for the Post-Project case. Notice from Table 3 that all of the voltages are between 0.95 p.u. and 1.05 p.u. prior to adding the project and for the most part the same applies for the post-project case except that for FLT13PH (highlighted in Table 4), the voltage at the Wind Project POI collapses.

Table 2: List of Contingencies

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

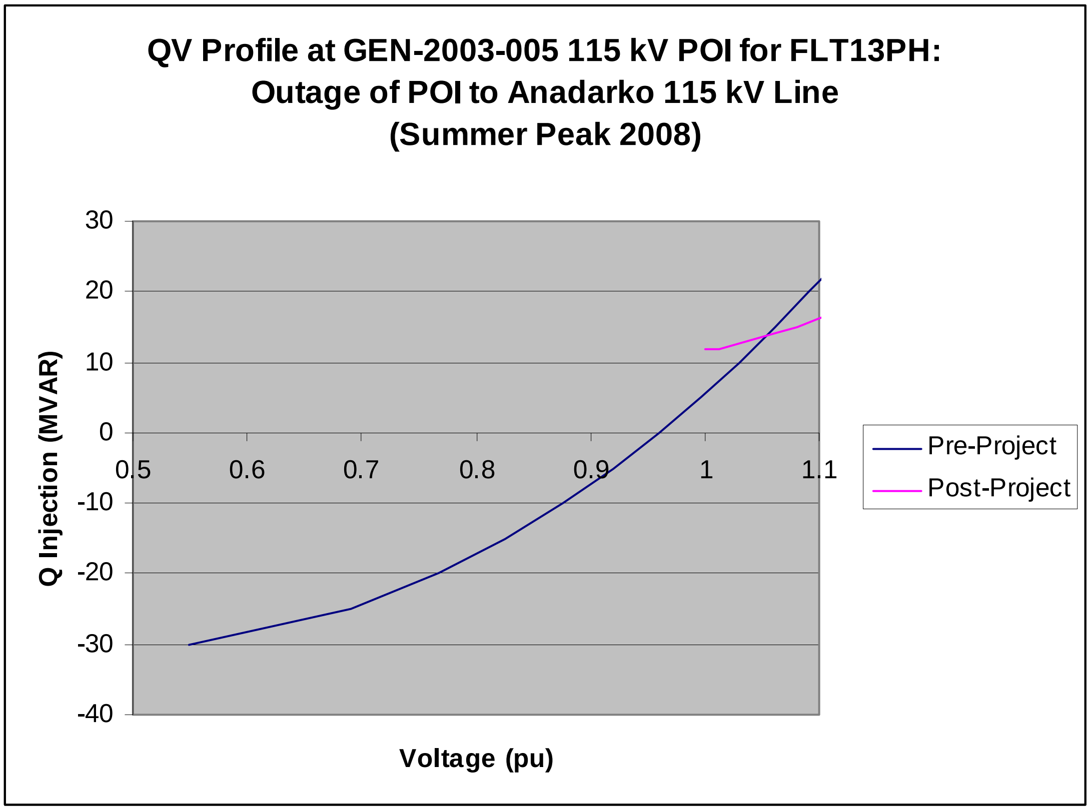
Table 3: Pre-Project Voltages at the POI

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

Table 4: Post-Project Voltages at the POI

Contingency Number	Voltage in p.u.	
	Summer Peak 08	Winter Peak 08
INTACT	1.0188	1.0254
FLT13PH	0.0444	0.0438
FLT33PH	1.0210	1.0249
FLT53PH	1.0199	1.0242
FLT73PH	1.0203	1.0270
FLT93PH	1.0179	1.0253
FLT113PH	1.0182	1.0266
FLT153PH	1.0184	1.0242
FLT173PH	1.0191	1.0267
FLT193PH	1.0186	1.0256
FLT213PH	1.0151	1.0210

QV analysis results for the FLT13PH contingency indicate that prior to the interconnection; the reactive power margin at the POI is 30 MVAR for summer and 33 MVAR for winter. After the interconnection, there is no reactive power margin left, but rather a deficit in reactive power, which is required for voltage stability. Summer voltages at the POI cannot be lower than 1.00 pu and winter voltages at the POI cannot be lower than 1.01 pu. Notice from Figure 1, summer peak case, that 11.9 MVAR injection at the 138 kV POI is required to hold the voltage at 1.00 pu and for the winter case, 9 MVAR injection is required to hold the voltage at 1.01 pu.



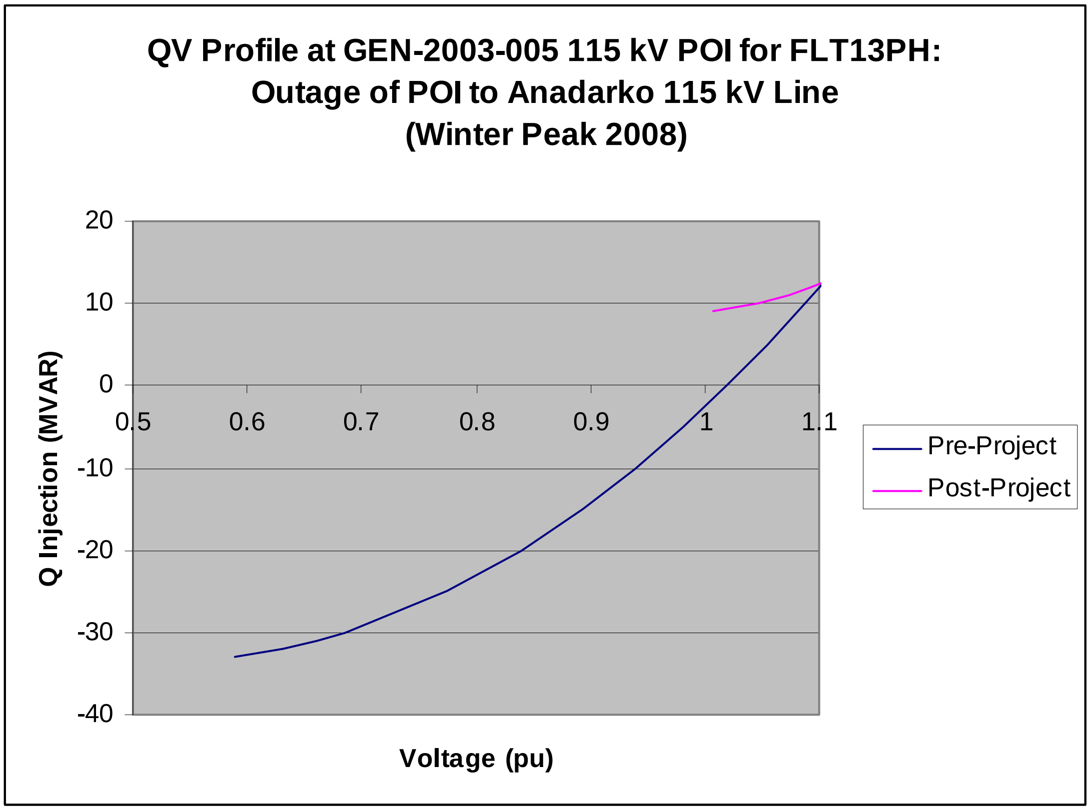


Figure 1: QV Analysis of pre-project and post-project cases
for summer peak (above) and winter peak (below)

Mechanically switched shunt capacitors (MSSC), STATCOM or both at 34.5 kV or/and 138 kV are needed for steady-state reactive power support. To avoid marginal stability for the FLT13PH contingency, the summer voltage schedule at the POI should be set to 1.017 pu, which is higher than 1.00 pu and consistent with the pre-project system intact voltage at the POI. The winter voltage schedule should be set to 1.0191 pu, which is higher than 1.01 pu and consistent with the pre-project FLT13PH contingency voltage at the POI. Table 5 summarizes the power factor requirements at the POI for the FLT13PH contingency. Essentially, the project needs to supply sufficient reactive power to meet unity power factor at the POI when the Anadarko – Wind Farm POI 138 kV line is offline. Figure 2 and 3 are power flow single-line diagrams of the summer and winter cases for the FLT13PH contingency. A VAR Generator has been added to Bus 003-005T, the POI, to provide the amount of reactive power compensation required to meet the voltage schedule.

Table 5: Post-Project Power Factor Requirements at the POI

Case	Voltage at POI (pu)	MW into POI	MVAR into POI			Power Factor at POI in %	
			Wind Project	VAR Generator at POI	Net		
Summer Peak 08	1.0170	99.0	-13.9	12.3	-1.6	100.0	lagging (inductive)
Winter Peak 08	1.0191	99.0	-13.0	9.2	-3.8	99.9	lagging (inductive)

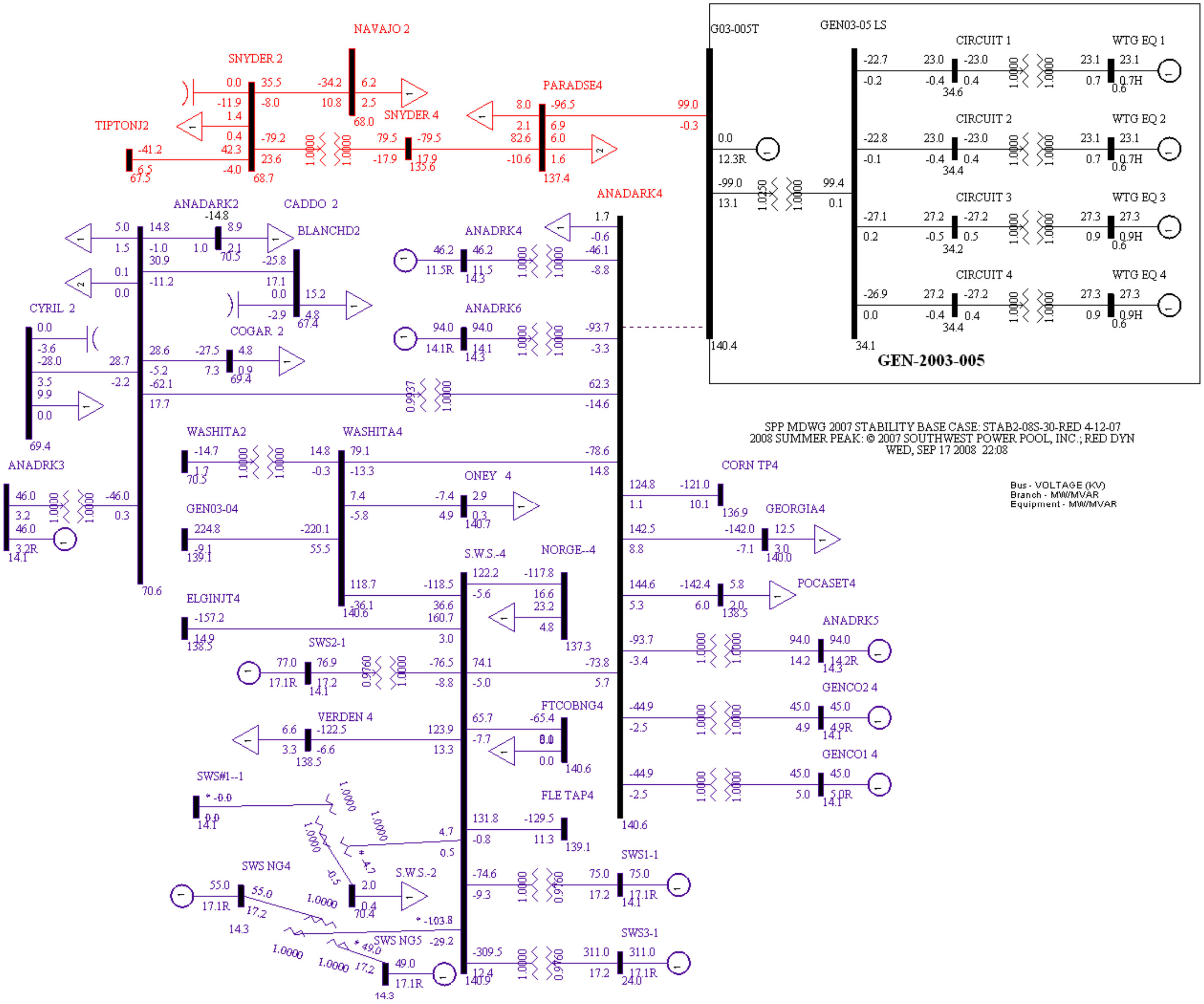


Figure 2: Post-Project Summer Peak 2008 for FLT13PH with VAR Generator at 003-005T, the POI

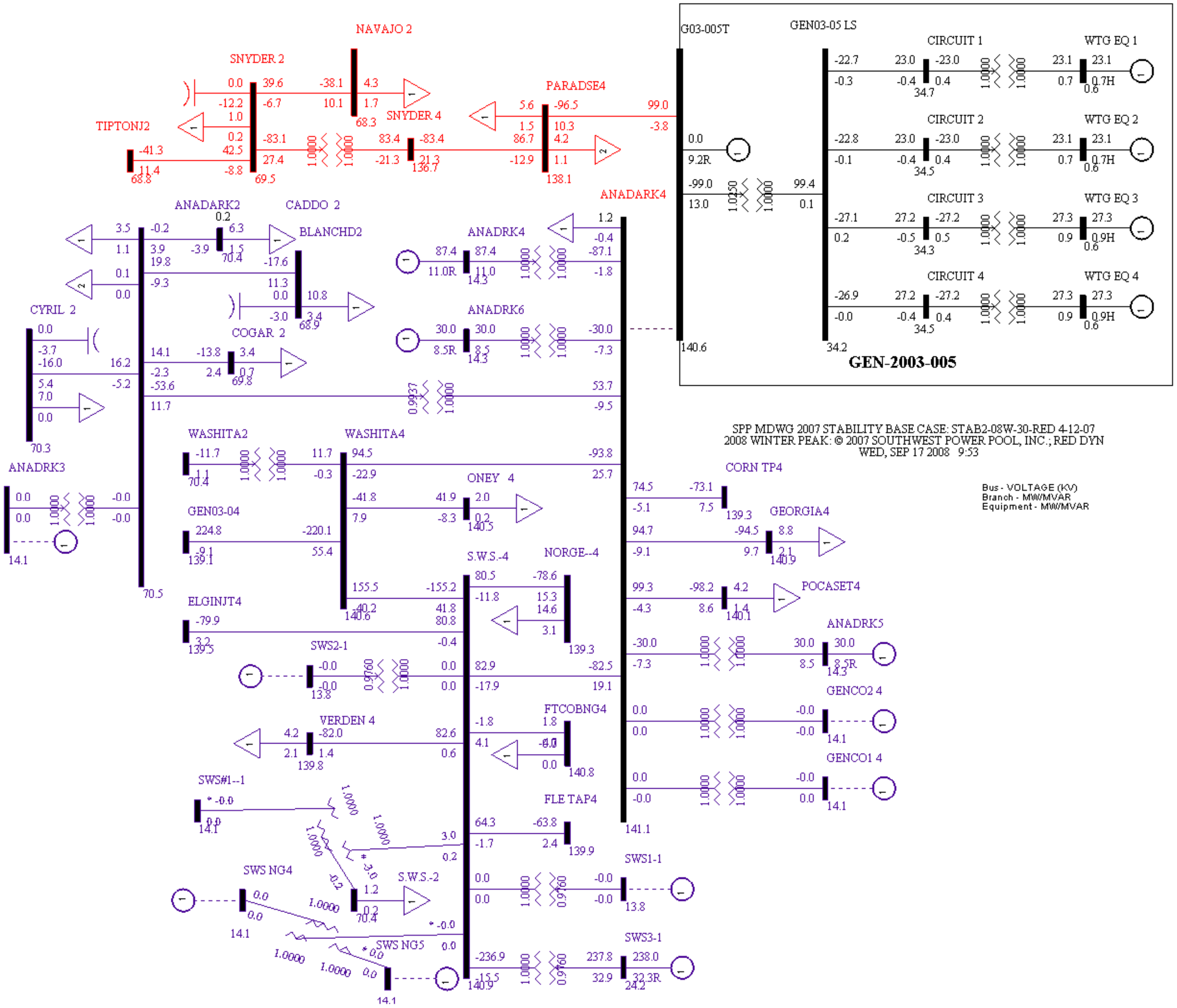


Figure 3: Post-Project Winter Peak 2008 for FLT13PH with VAR Generator at Bus 003-005T, the POI

3. DYNAMIC STABILITY SIMULATIONS AND RESULTS

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

Table 6: Fault Contingencies Evaluated

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

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

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

Control areas monitored:

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

Prior queued projects monitored:

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

3.1. Stability Criteria

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

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

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

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

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

3.2. Modeling of Wind Turbine Generators

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

3.3. Pre-Project Simulation Results

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

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

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

Pre-project study results are summarized in Table 10 for fault contingencies in Table 6.

3.4. Post-Project Simulation Results

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

Summer Peak 2008

Nearby areas are stable for fault contingencies #3 thru #20. However, the project will disconnect for faults #1 and #2 on low voltage relay actuation of **UV Relay 5** as shown in Figure 4. As a result, the interconnection does not satisfy the low voltage ride through provisions in FERC Order 661A. Furthermore, simulations indicate that voltages in the wind farm, as shown in Figure 5, and nearby connected buses will become unstable when fault #1 and #2 are re-studied with the voltage and frequency protection settings of the Suzlon wind turbine generators disabled.

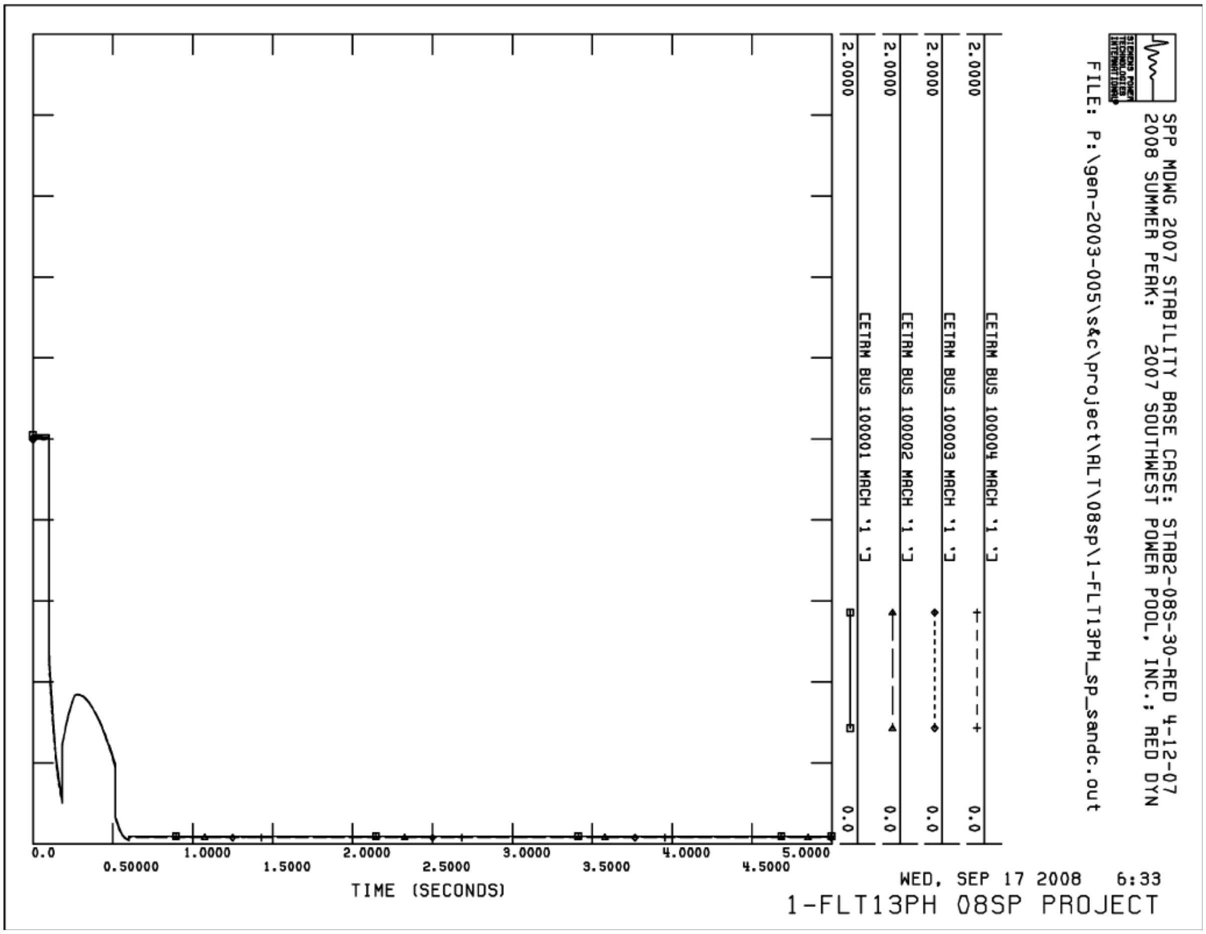


Figure 4: Suzlon terminal voltages for fault #1 - Table 6 (Summer Peak)

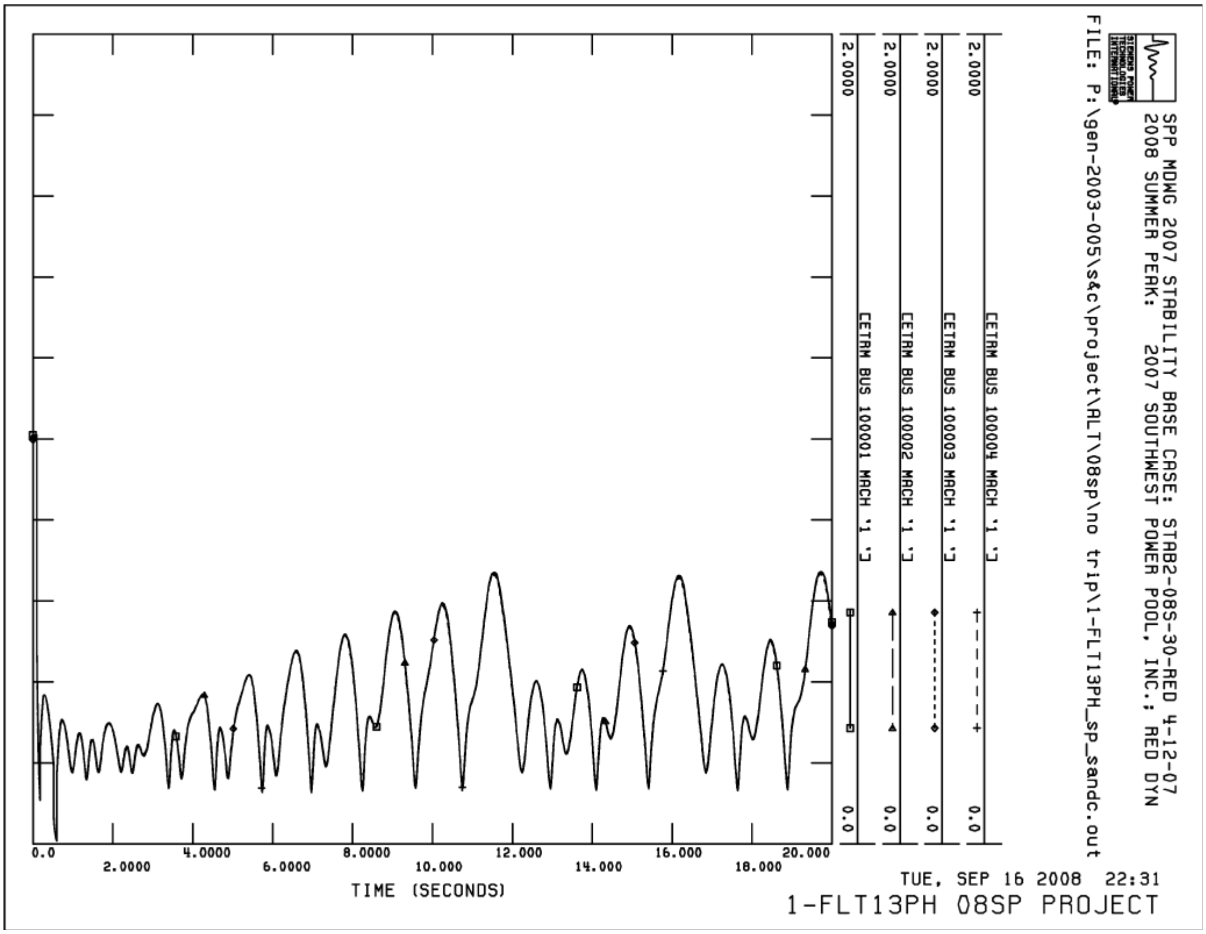


Figure 5: Suzlon terminal voltages for fault #1 - Table 6 (Summer Peak)
with voltage and frequency protection disabled

Sensitivity analysis indicates that a +/- 9 MVA STATCOM with 2-second short-time rating of +/-23.76 MVA (2.64 pu) located at the 34.5 kV collector bus will provide the high-speed and smooth reactive supply required to keep the project connected and retain system stability. The output/performance of the STATCOM for fault #1 is shown in figure 6. Figure 7 and 8 shows tthe wind farm will satisfy the FERC 661A LVRT provisions with the proposed STATCOM device. Simulations were performed using the generic PSS/E library model CSTATT. Sensitivity analysis used 1 MVAR increments of STATCOM rating. In this arrangement, the STATCOM controls the 34.5 kV collector bus voltage to 1.00 pu. There is also need for a 3.6 MVAR MSSC located at the 138 kV POI as shown in figure 9. This MSSC is intended for steady-state reactive power support and should stay online unless voltages are above 1.05 pu at the POI. Performance of the STATCOM device may be subject to differences from manufacturer to manufacturer; therefore, a sizing study using device specific dynamic models regardless of the results of this study must demonstrate that the proposed device will keep the project connected and maintain system stability.

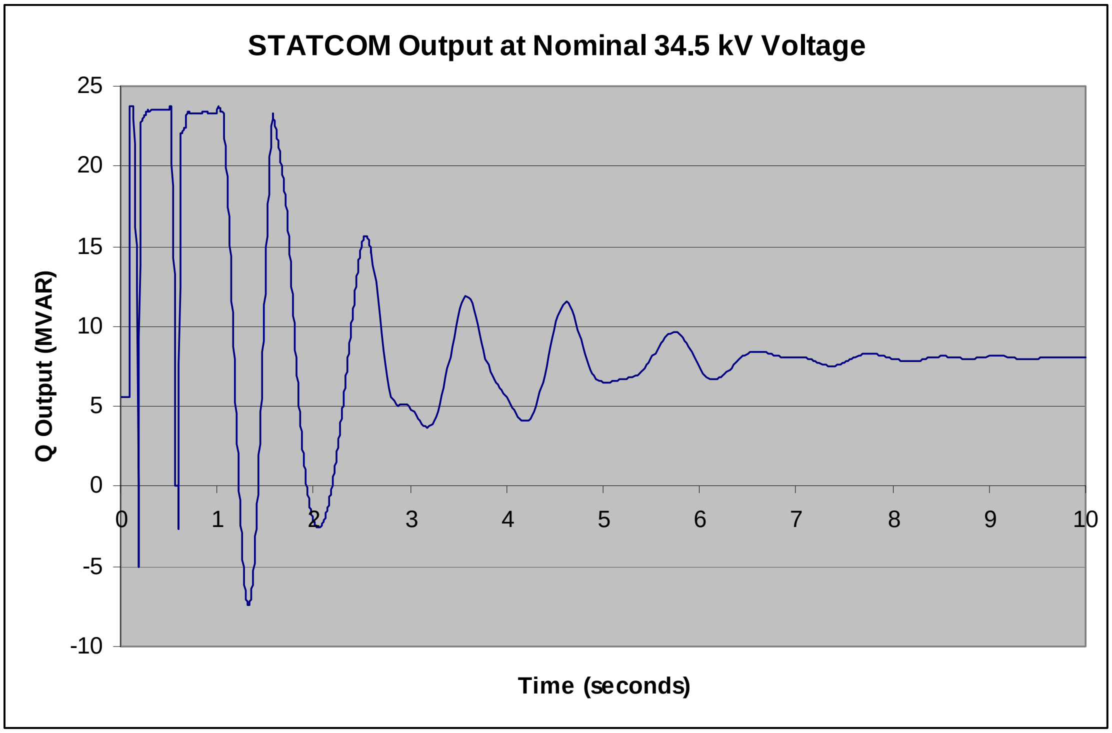


Figure 6: Output of +/- 9 MVAR STATCOM with short-time rating of +/- 23.76 MVAR at rated 34.5 kV voltage for fault #1 - Table 6 (Summer Peak)

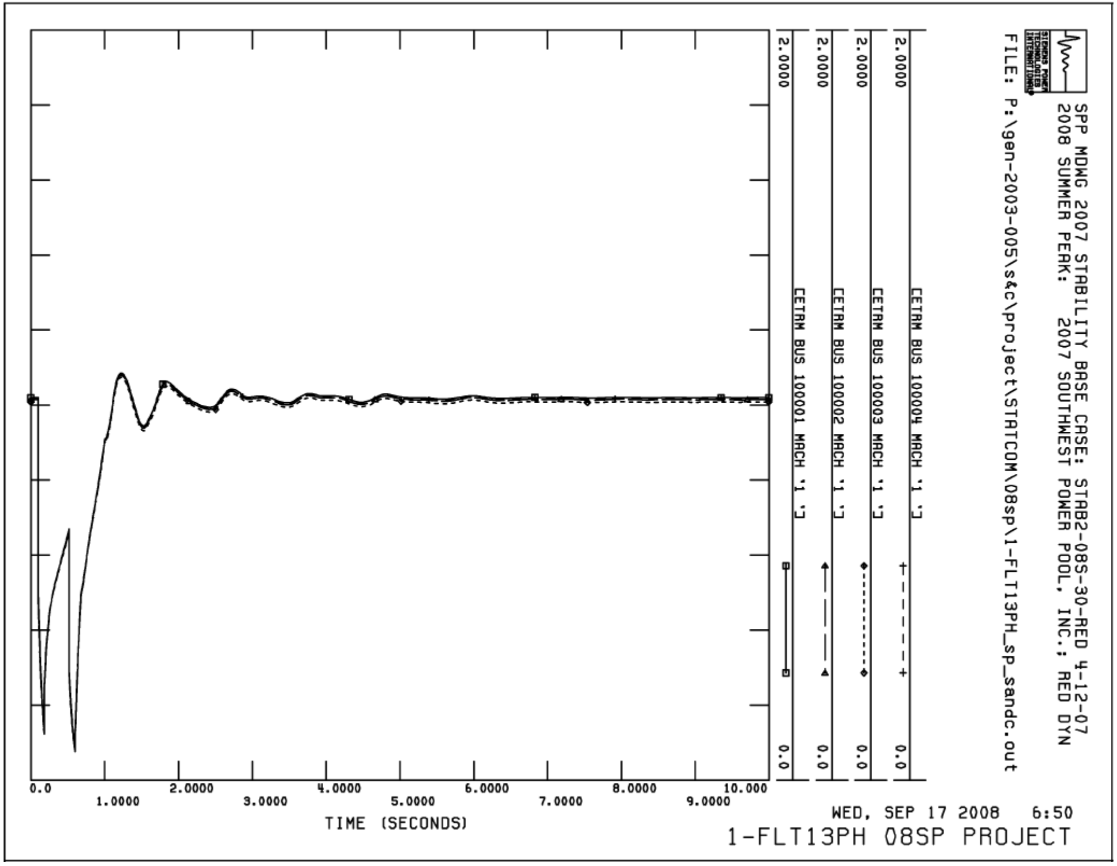


Figure 7: Suzlon terminal voltages for fault #1 - Table 6 with +/- 9 MVAR STATCOM at 34.5 kV and 3.6 MVAR MSSC at 138 kV (Summer Peak)

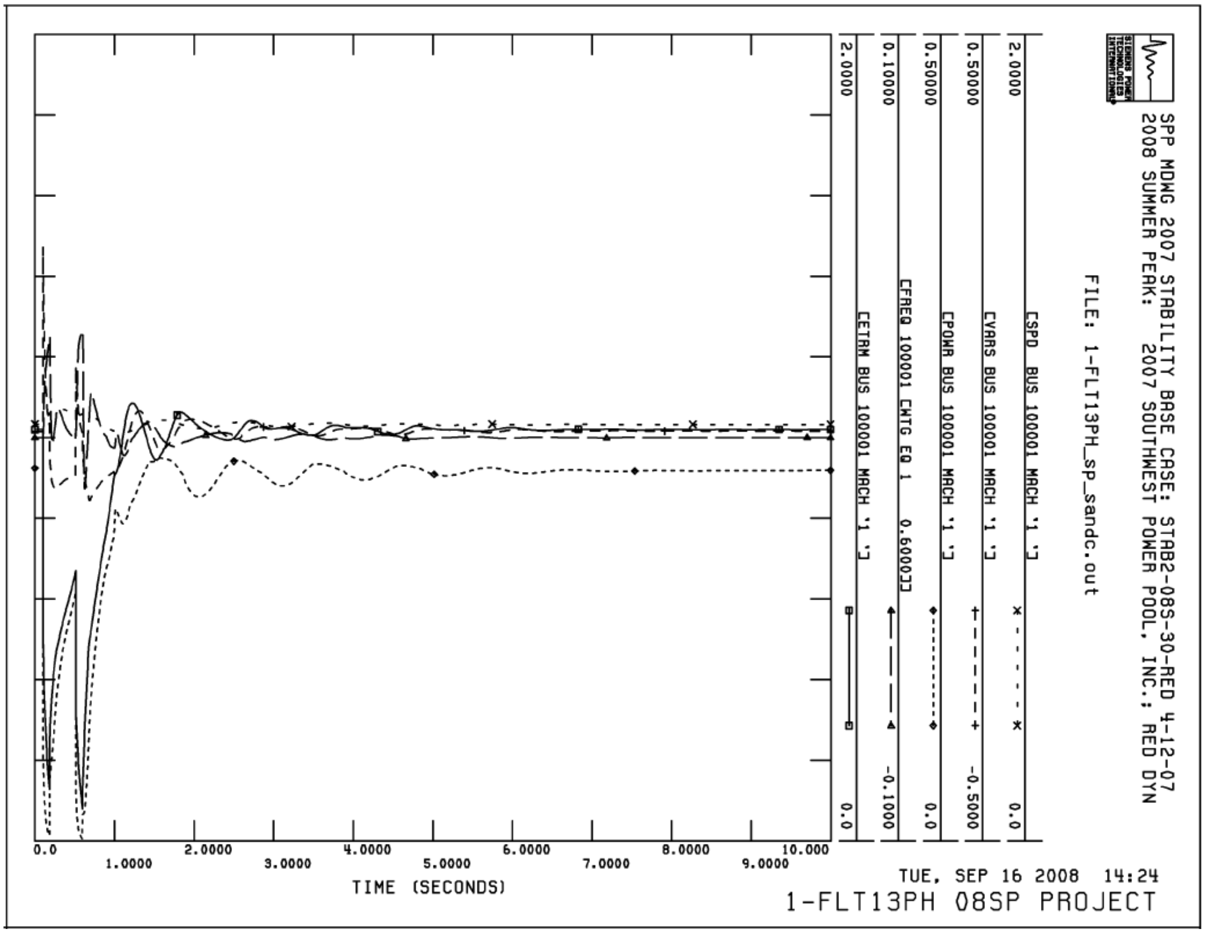


Figure 8: Suzlon terminal voltages, frequency, output power, and speed for fault #1 - Table 6 with +/- 9 MVAR STATCOM at 34.5 kV and 3.6 MVAR MSSC at 138 kV (Summer Peak)

The proposed reactive compensation system will meet the power factor and voltage requirements previously covered in Section 2.2. Post-project voltages at the POI for each of the contingencies from Table 2 are shown in Table 8.

Transient stability results are summarized in Table 10 for fault contingencies in Table 6.

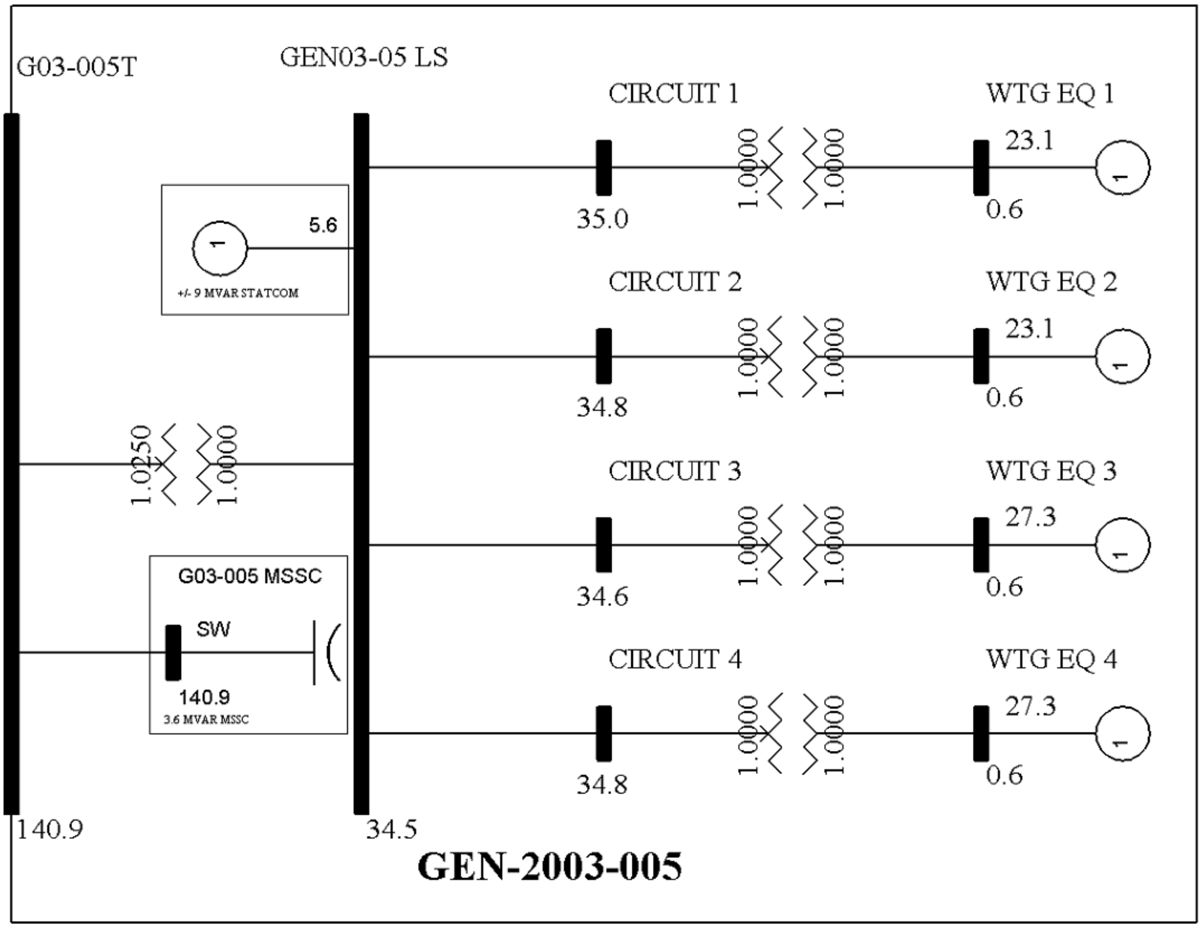


Figure 9: Reactive compensation arrangement with +/- 9 STATCOM at 34.5 kV and 3.6 MVAR MSSC at 138 kV (Summer Peak)

Table 8: Post-Fault Voltages at the POI (Summer Peak)

Contingency Number	Voltage in p.u.
INTACT	1.0213
FLT13PH	1.0173
FLT33PH	1.0232
FLT53PH	1.0223
FLT73PH	1.0225
FLT93PH	1.0206
FLT113PH	1.0211
FLT153PH	1.0210
FLT173PH	1.0217
FLT193PH	1.0212
FLT213PH	1.0185

Winter Peak 2008

Likewise for the winter case, results show that nearby areas are stable for fault contingencies #3 thru #20, but the project will disconnect for faults #1 and #2 on low voltage relay actuation of **UV Relay 5** and when faults #1 and #2 are re-studied with the Suzlon protection disabled, the project as well as nearby connected buses will become unstable. The interconnection does not satisfy the low voltage ride through provisions in FERC Order 661A, but the proposed +/- 9 MVA STATCOM with 2-second short-time rating of +/-23.76 MVA (2.64 pu) located at the 34.5 kV collector bus will provide the high-speed and smooth reactive supply required to keep the project connected and retain system stability. Figure 10 and 11 show the wind farm will satisfy the FERC 661A LVRT provisions with the proposed STATCOM device.

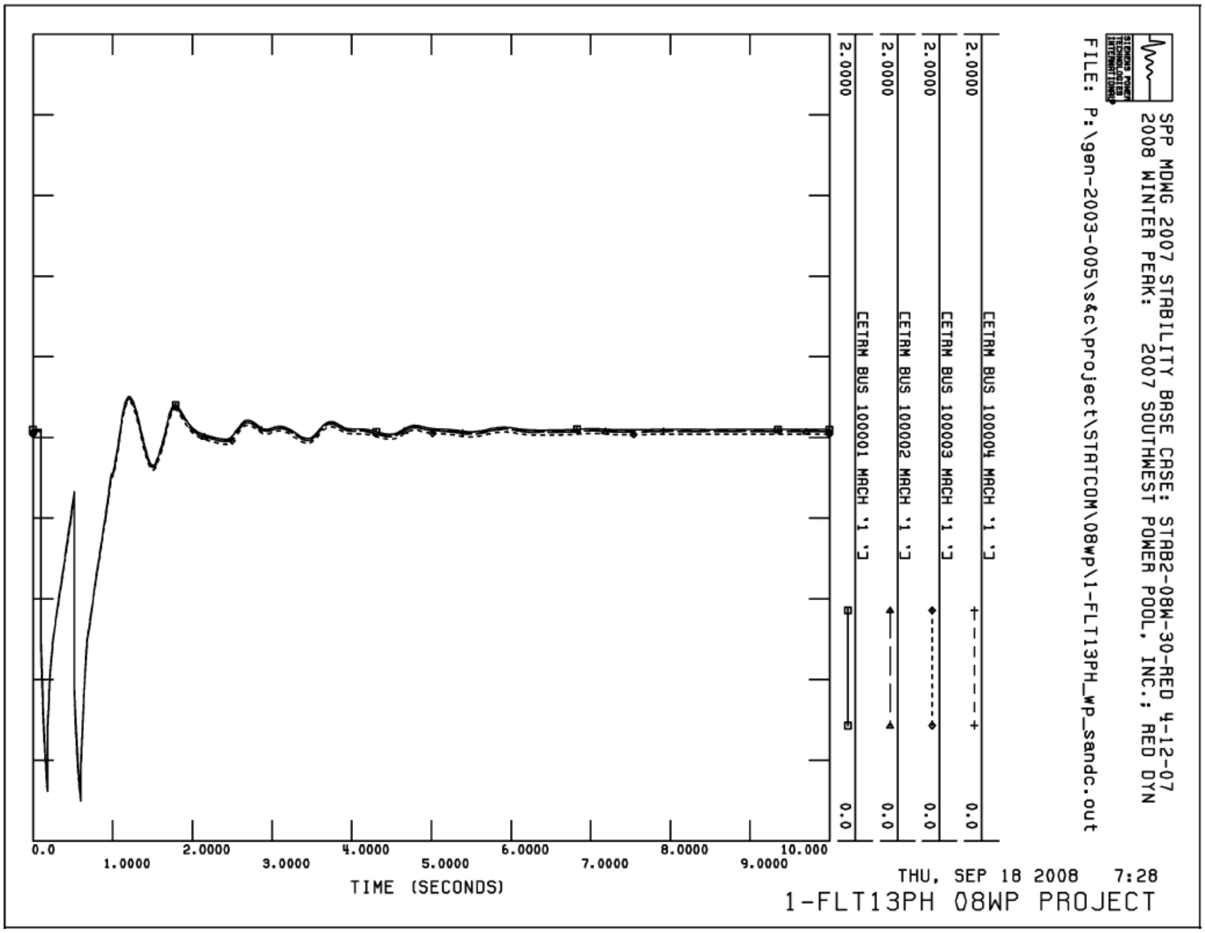


Figure 10: Suzlon terminal voltages for fault #1 - Table 6 with +/- 9 MVAR STATCOM at 34.5 kV and 3.6 MVAR MSSC at 138 kV (Winter Peak)

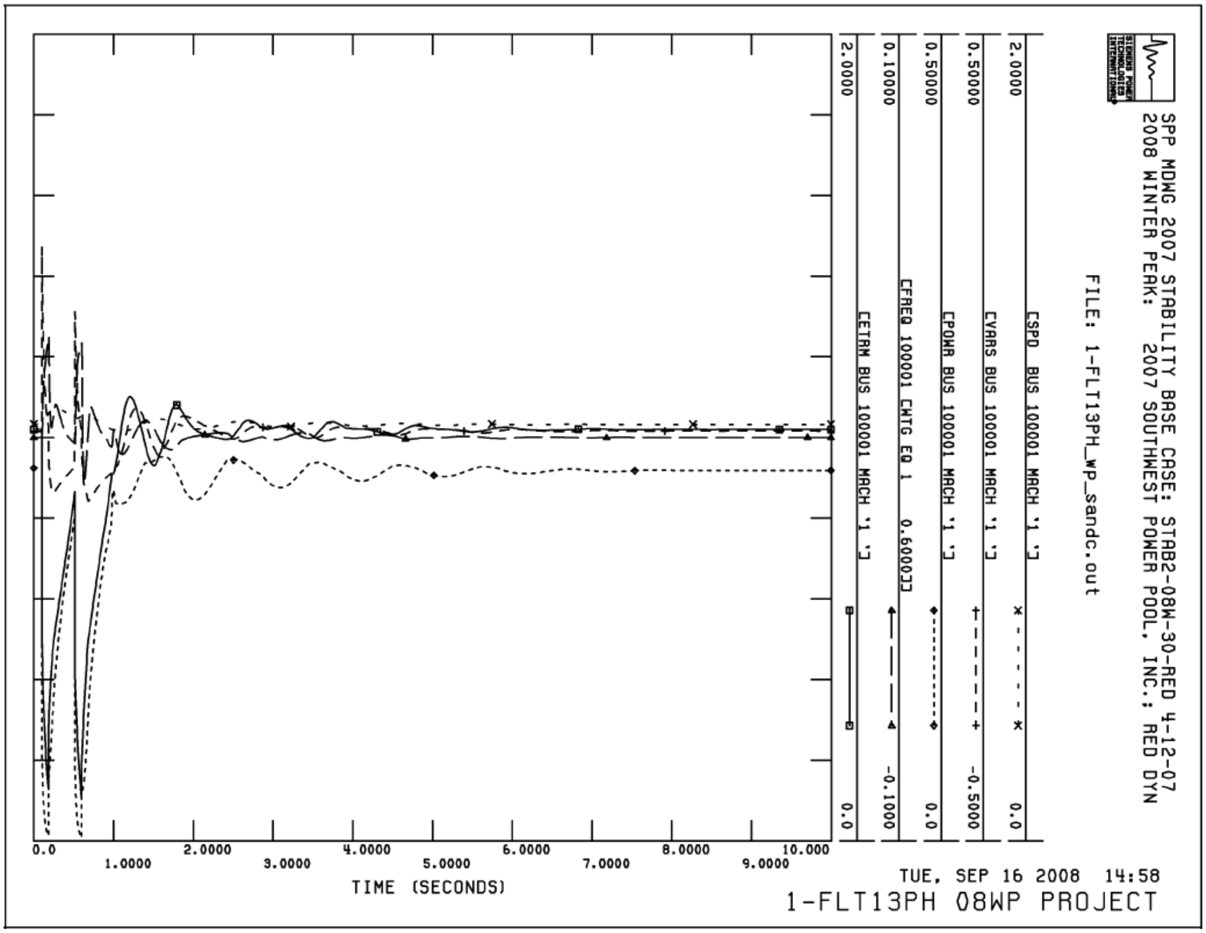


Figure 11: Suzlon terminal voltages, frequency, output power, and speed for fault #1-Table 6 with +/- 9 MVAR STATCOM at 34.5 kV and 3.6 MVAR MSSC at 138 kV (Winter Peak)

Also the proposed reactive compensation system will meet the power factor and voltage requirements previously covered in Section 2.2. There is need for a 3.6 MVAR MSSC located at the 138 kV POI for steady-state reactive power support that is intended to be normally online unless the voltages are above 1.05 pu. Post-project voltages at the POI for each of the contingencies from Table 2 are shown in Table 9.

Transient stability results are summarized in Table 10 for fault contingencies in Table 6.

Table 9: Post-Fault Voltages at the POI (Winter Peak)

Contingency Number	Voltage in p.u.
INTACT	1.0269
FLT13PH	1.0218
FLT33PH	1.0266
FLT53PH	1.0260
FLT73PH	1.0282
FLT93PH	1.0268
FLT113PH	1.0281
FLT153PH	1.0266
FLT173PH	1.0281
FLT193PH	1.0271
FLT213PH	1.0235

Table 10: Summary of Transient Stability Analysis Results

Fault No.	*Description*	Summer Peak 2008			Winter Peak 2008		
			Post-project			Post-project	
		Pre-project	Without STATCOM	With STATCOM	Pre-project	Without STATCOM	With STATCOM
1	Three phase fault on Anadarko (#520814) – Wind Farm 138 kV line, near the Wind Farm	STABLE	INSTABLE GEN-2003-005 trips off on undervoltage	STABLE	STABLE	INSTABLE GEN-2003-005 trips off on undervoltage	STABLE
2	Single phase fault like FLT13PH	STABLE	INSTABLE GEN-2003-005 trips off on undervoltage	STABLE	STABLE	INSTABLE GEN-2003-005 trips off on undervoltage	STABLE
3	Three phase fault on Paradise (#521024) – Windfarm 138 kV line, near the wind farm	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
4	Single phase fault like FLT33PH.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
5	Three phase fault on Snyder (#521052) – Paradise (521024) 138 kV line, near Snyder	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Summer Peak 2008			Winter Peak 2008		
		Pre-project	Post-project		Pre-project	Post-project	
			Without STATCOM	With STATCOM		Without STATCOM	With STATCOM
6	Single phase fault like FLT53PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
7	Three phase fault on Snyder (#521051) – Navajo (#521009) 69kV line, near Snyder	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
8	Single phase fault like FLT73PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
9	Three phase fault on Fort Cobb (#511454)– Southwestern Station (#511477) 138 kV line, near Fort Cobb	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
10	Single phase fault like FLT93PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Summer Peak 2008			Winter Peak 2008		
		Pre-project	Post-project		Pre-project	Post-project	
			Without STATCOM	With STATCOM		Without STATCOM	With STATCOM
11	Three phase fault on Anadarko (#520814) – Southwestern Station (#511477) 138 kV line, near Southwestern Station	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
12	Single phase fault like FLT113PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
13	Three phase fault on Anadarko (#520810) – Blanchard (#520828) 69 kV line, near Blanchard	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
14	Single phase fault like FLT153PH..	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Summer Peak 2008			Winter Peak 2008		
		Pre-project	Post-project		Pre-project	Post-project	
			Without STATCOM	With STATCOM		Without STATCOM	With STATCOM
15	Three phase fault on Washita (#521089) – Anadarko (#520814) 138 kV line, near Anadarko	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
16	Single phase fault like FLT173PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
17	Three phase fault on Washita (#521089) – Oney (#521017) 138 kV line, near Oney	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
18	Single phase fault like FLT193PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Fault No.	*Description*	Summer Peak 2008			Winter Peak 2008		
			Post-project			Post-project	
		Pre-project	Without STATCOM	With STATCOM	Pre-project	Without STATCOM	With STATCOM
19	Three phase fault on Washita (#521089) – Southwest Station (#511477) 138 kV line, near Washita, with one shot reclosing after 30 cycles.	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE
20	Single phase fault like FLT213PH	STABLE	STABLE	STABLE	STABLE	STABLE	STABLE

Summer Peak 2008 and Winter Peak 2008 using S&C PureWave DSTATCOM® Distributed Static Compensator

Another possibility is to relocate the 3.6 MVAR MSSC to the 34.5 kV collector bus. The STATCOM also located at the 34.5 kV collector bus voltage will control the voltage at the 138 kV POI to a preset voltage schedule. The 3.6 MVAR MSSC is intended to be normally online unless the voltages are above 1.05 pu at the POI. Because the PSS/E CSTATT model cannot control a remote bus, the user-defined S&C PureWave DSTATCOM model was used in its place to demonstrate in general the feasibility of this approach. A +/- 8.75 MVAR DSTATCOM with short-time rating of +/-23.10 MVAR will provide the high-speed and smooth reactive supply required to keep the project connected and retain system stability. Study results are shown in Figure 13.

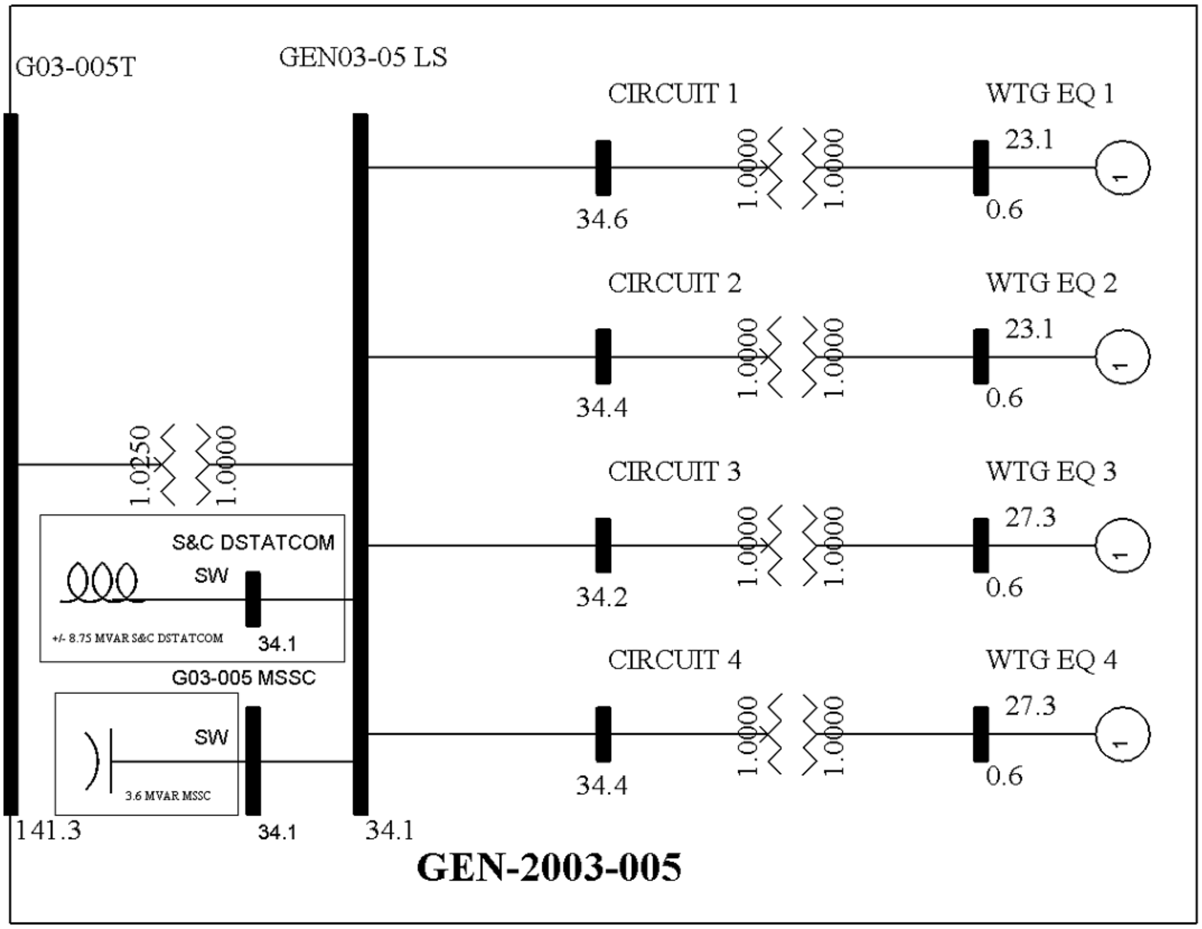


Figure 12: Reactive compensation arrangement with +/- 8.75 MVAR DSTATCOM with +/-23.1 MVAR short-time capability at 34.5 kV and 3.6 MVAR MSSC at 34.5 kV

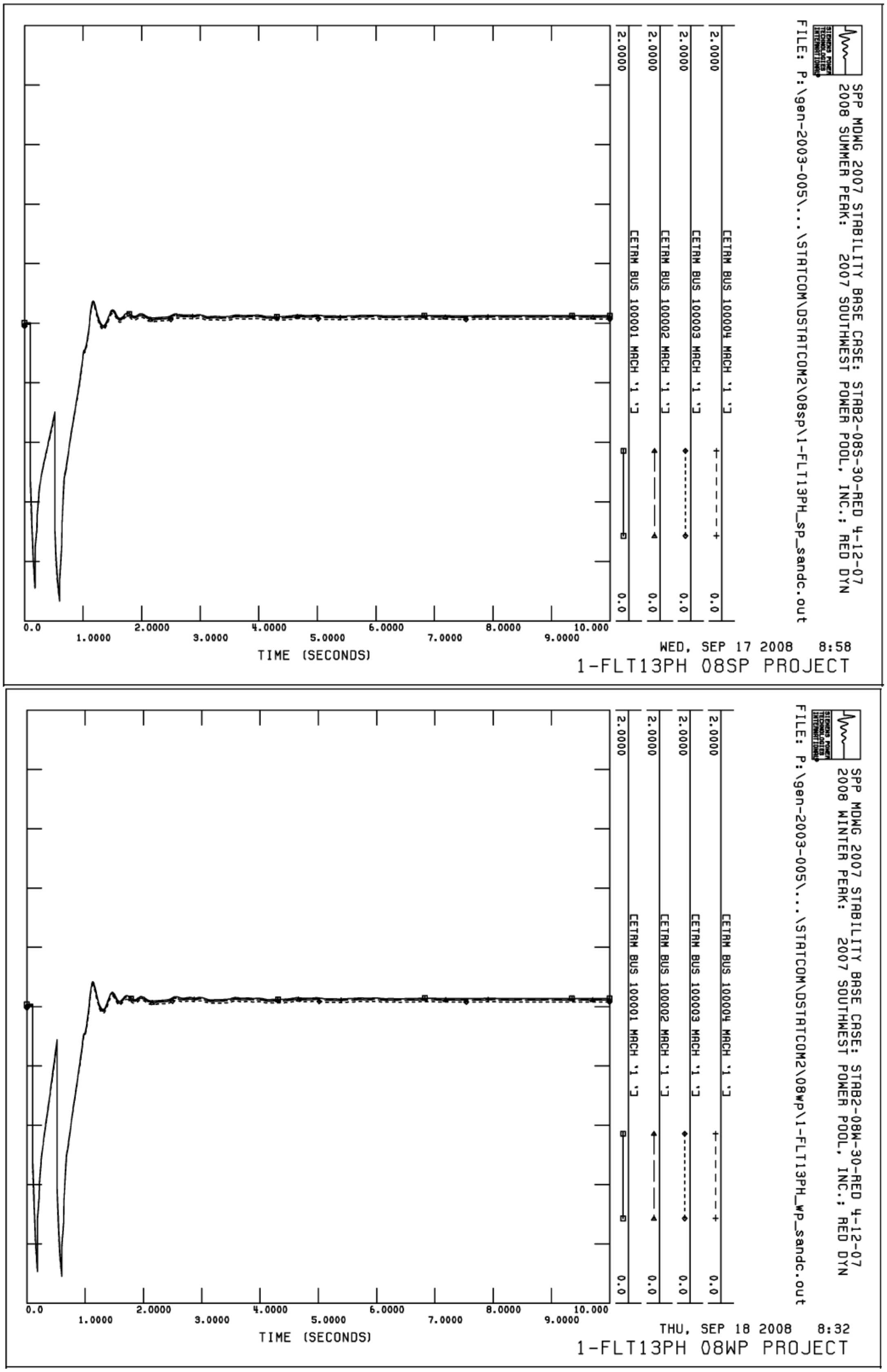


Figure 13: Suzlon terminal voltages for fault #1 - Table 6 with +/- 8.75 MVAR DSTATCOM at 34.5 kV and 3.6 MVAR MSSC at 34.5 kV for Summer (above) and Winter (below)

To demonstrate the ability of this system to control the voltage at the 138 kV to a voltage schedule, the voltage schedules from Table 5 are used. Post-fault voltages at the POI are summarized in Table 11.

Table 11: Post-Fault Voltages at the POI

Contingency Number	Voltage in p.u.	
	Summer Peak 08	Winter Peak 08
INTACT	1.0174	1.0239
FLT13PH	1.0170	1.0191
FLT33PH	1.0195	1.0233
FLT53PH	1.0184	1.0226
FLT73PH	1.0188	1.0254
FLT93PH	1.0170	1.0238
FLT113PH	1.0170	1.0248
FLT153PH	1.0170	1.0234
FLT173PH	1.0176	1.0250
FLT193PH	1.0172	1.0240
FLT213PH	1.0170	1.0193

4. CONCLUSIONS AND RECOMMENDATIONS

1. Need has been identified for mechanically switched shunt capacitors (MSSC), STATCOM or both at 34.5 kV or/and 138 kV for steady-state reactive power support. The project needs to supply sufficient reactive power to meet unity power factor at the POI when the Anadarko – Wind Farm POI 138 kV line is offline. This power factor requirement can be met through the use of switched capacitor banks, STATCOM, or a combination of the two.

2. High-speed reactive power support is needed to help the turbines ride thru the fault and satisfy the FERC Order 661A provisions on low-voltage ride through (LVRT). Suzlon wind turbine generators will disconnect on low voltage relay actuation for faults near the project on the POI – Anadarko 138 kV line. <u>Either a STATCOM or SVC can be used for this purpose and is a requirement for the interconnection of this generation interconnection request</u>.

3. +/- 9 MVA STATCOM with 2-second short-time rating of +/-23.76 MVA (2.64 pu) located at the 34.5 kV collector bus will provide the high-speed and smooth reactive supply required to keep the project connected and retain system stability.

4. The +/- 9 MVAR STATCOM has a continuous range that can be used for steady-state reactive power support, but it is still not sufficient and an additional 3.6 MVAR MSSC is needed either at 34.5 kV or 138 kV.

5. Two approaches were studied that will work:
   i. MSSC at the 138 kV POI and STATCOM at the 34.5 kV collector bus
   ii. Both MSSC and STATCOM at the 34.5 kV collector bus