Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2003 – 004

SPP Coordinated Planning
(#GEN-2003-004)

April 2004

Summary

Black & Veatch (B&V) performed the following study at the request of the Southwest Power Pool (SPP) for SPP Generation Interconnection request Gen-2003-004. The request for interconnection was placed with SPP in accordance SPP's Open Access Transmission Tariff Attachment V, which covers new generation interconnections on SPP's transmission system.

Pursuant to the tariff, B&V was asked to perform a detailed stability analysis of the generation interconnection requests to satisfy the System Impact Study Agreement executed by the requesting customer and SPP.

The Customer requested that the study cover using two different wind turbine machines and three MW levels.

IMPACT STUDY FOR SPP GENERATION

QUEUE POSITION GEN-2003-004

SOUTHWEST POWER POOL (SPP)

April 2004

By

BLACK & VEATCH

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EXECUTIVE SUMMARY

A transient stability study has been performed for Southwest Power Pool (SPP) Interconnection Queue Position Gen-2003-004 as part of the System Impact Study. The Interconnection Queue Position Gen-2003-004 is an additional 100 MW wind farm (Phase II) to a previously studied 75 MW facility (Phase I) located near Apache, Oklahoma.

The wind farm will be interconnected to the Washita switching station owned by Western Farmers Electric Cooperative (WFEC) with a 24.5 mile radial 138 kV transmission line. The Phase I portion of the wind farm consists of NEG Micon turbines.

Customer has requested the System Impact Study for Phase II of the project include NEG Micon and GE 1.5 MW as possible options.

The 2009 summer peak load flow case together with the SPP MDWG 2003 stability model were used as the base case for the transient stability analysis. The study was performed using PTI's PSS/E program, which is an industry-wide accepted power system simulation program. The NEG Micon and GE 1.5 MW wind generators were modeled using the induction generator model and the GE wind turbine model respectively available in PSS/E.

Transient Stability studies were conducted with the Phase II (Gen-2003-004) output at 100 MW (100%), 80 MW (80%) and 50 MW (50%). The Phase I output was considered at its full capacity in all the simulations. Sixteen (16) contingencies were considered for each of the 100%, 80% and 50% cases, with both NEG Micon and GE 1.5 MW turbines.

The study has not indicated any angular or voltage instability problem for the contingencies analyzed in both the options. However, the study has indicated that the GE 1.5 MW turbines will have to be provided with the low voltage ride through facility (15% for 500 mS) in order to continue the operation during the grid faults.

Based on the study results, the Customer shall discuss with GE, the turbine manufacturer, the new control and protection packages available for the GE 1.5 MW wind turbines which would enable the turbine generators to ride through low voltages.

The new Washita – Southwestern Station 138 kV transmission line was also included in the computer model. The estimated cost of this new transmission line with the upgrade for Southwestern Station is about $2,400,000.

If any previously queued projects that were included in this study drop out then this System Impact Study may have to be revised to determine the impacts of this Interconnection Customer's project on WFEC transmission facilities.

1. INTRODUCTION

This report discusses the results of a transient stability study performed for Southwest Power Pool (SPP) Interconnection Queue Position Gen-2003-004.

The Interconnection Queue Position Gen-2003-004 is an additional 100 MW wind farm (Phase II) to a previously studied 75 MW facility (Phase I) located near Apache, Oklahoma. The wind farm will be interconnected to the Washita switching station owned by Western Farmers Electric Cooperative (WEFC) with a 24.5 mile radial 138 kV transmission line. The system one line diagram of the area near the Queue Position Gen-2003-004 is shown in below.

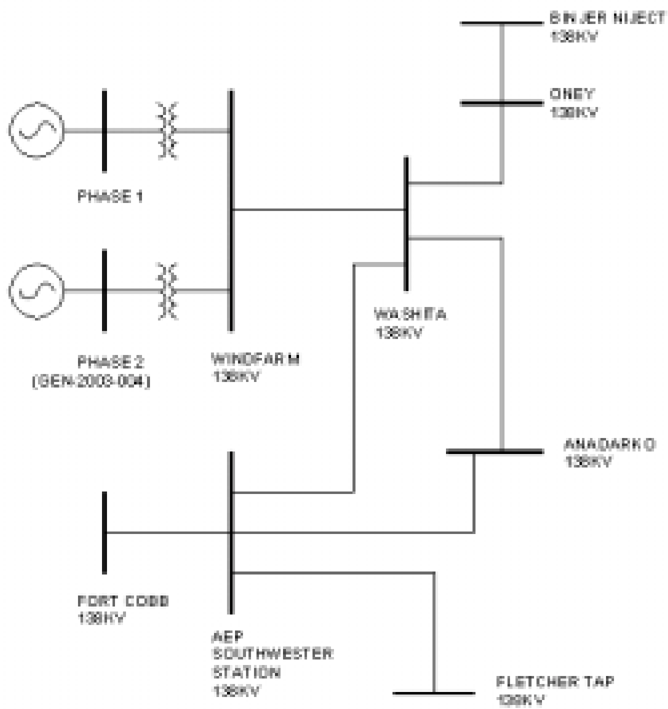


Figure 1 : System One Line Diagram near GEN-2003-004

Transient Stability studies were conducted with the Phase II (Gen-2003-004) output at 100 MW (100%), 80 MW (80%) and 50 MW (50%).

The Phase I portion of the wind farm consists of NEG Micon turbines and the Phase II portion of the wind farm will either contain NEG Micon or GE 1.5 MW turbines. Hence, both NEG Micon and GE 1.5 MW wind turbines have been considered in this study.

2. STABILITY STUDY CRITERIA

The 2009 summer peak load flow case together with the SPP MDWG 2003 stability model were used as the base case for the transient stability analysis. These models were provided by SPP.

Using Planning Standards approved by NERC, the following stability definition was applied in the Transient Stability Analysis:

"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."

Disturbances such as three phase and single phase line faults were simulated for a specified duration and the synchronous machine rotor angles were monitored for their synchronism following the fault removal. In addition to the verification of synchronism by plotting the machine angles with respect to time, the automatic built-in "loss of synchronism" scanning feature of the PSS/E was also utilized.

The ability of the wind generators to stay connected to the grid during the disturbances and during the fault recovery was also monitored.

3. SIMULATION CASES

Transient Stability studies were conducted with the Phase II (Gen-2003-004) output at 100 MW (100%), 80 MW (80%) and 50 MW (50%). The Phase I output was considered at its full capacity in all the simulations.

Table 1 indicates the contingencies which were studied for each of the three (100%, 80% and 50%) cases.

Fault Number	Fault Definition
FLT13PH	Three phase fault on Washita – Wind Farm 138 kV line, closer to the Wind Farm.
FLT21PH	Single phase fault on Washita – Wind Farm 138 kV line, closer to the Wind Farm.
FLT33PH	Three phase fault on Washita – Anadarko 138 kV line, closer to Anadarko.
FLT41PH	Single phase fault on Washita – Anadarko 138 kV line, closer to Anadarko.

Table 1: Study Cases

FLT53PH	Three phase fault on Southwester Station – Anadarko 138 kV line, closer to Southwester Station.
FLT61PH	Single phase fault on Southwester Station – Anadarko 138 kV line, closer to Southwester Station.
FLT73PH	Three phase fault on Southwester Station – Fort Cobb 138 kV line, closer to Fort Cobb.
FLT81PH	Single phase fault on Southwester Station – Fort Cobb 138 kV line, closer to Fort Cobb.
FLT93PH	Three phase fault on Fletcher tap – Southwestern Station 138 kV line, closer to Fletcher tap.
FLT101PH	Single phase fault on Fletcher tap – Southwestern Station 138 kV line, closer to Fletcher tap.
FLT113PH	Three phase fault on Washita – Oney 138 kV line, closer to Oney.
FLT121PH	Single phase fault on Washita – Oney 138 kV line, closer to Oney.
FLT133PH	Three phase fault on Oney – Binger Niject 138 kV line, closer Binger Niject.
FLT141PH	Single phase fault on Oney – Binger Niject 138 kV line, closer Binger Niject.
FLT153PH	Three phase fault on Washita – Southwester Station 138 kV line, closer to Washita.
FLT161PH	Single phase fault on Washita – Southwester Station 138 kV line, closer to Washita.

Table 1: Study Cases (Cont'd)

In all of the simulations, the fault duration was considered to be 5 cycles. One shot re-closing into the fault was also considered in the study with the re-closure dead time of 20 cycles, except for the scenarios FLT93PH, FLT101PH, FLT153PH and FLT161PH. The re-closure dead time was considered to be 30 cycles for these four scenarios.

4. PHASE I MODELING

The Phase I portion of the wind farm consists of NEG Micon NM72 wind generators which are three phase asynchronous (squirrel cage induction) fixed speed machines. The following are the main electrical parameters of the NEG Micon NM72 wind generator:

Rated Power : 1,650 kW
Apparent Power : 1,808 kVA
Rated Reactive Power Consumption : 740 kVAR
Power Factor Compensation : 499.4 kVAR

The data for the NEG Micon wind generator, generator unit transformer and the substation transformer are indicated in Table 2.

Description	Value
Armature resistance, Ra	0.022 p.u.
Stator leakage reactance, Xl	0.087 p.u.
Synchronous reactance, Xd	3.65 p.u.
Transient reactance, Xd	0.089 p.u.
Open circuit transient time constant, Tdo	0.975 sec
Sub-transient reactance, Xd	0.05 p.u.
Open circuit sub-transient time constant, Tdo	0.975 sec
Inertia constant including turbine	4.87 sec
Generator unit transformer rating	1.65 MVA
Generator unit transformer impedance	5.74%
Substation transformer rating	100 MVA
Substation transformer impedance	15%

Table 2 : NEG Micon Generator Data

The Phase I project consists of 45 wind turbines with three collector buses. The Customer provided the Operational Diagram for Phase I. The three collector circuits are connected to a 34.5/138 kV substation, common to both Phase I and Phase II.

The Phase I project generators were modeled as 9 equivalent generators as per the Operational Diagram and the Customer provided single line diagram.

5. PHASE II WITH NEG MICON TURBINES

5.1 SIMULATION MODEL

The models of the Phase I and Phase II equipment such as generators, transformers and cables were added to the base case for the purpose of this study. The Operational Diagram for the Phase II portion of the wind farm was based on the number of collector circuits shown on the Customer provided single line diagram.

Table 3 provides the number of NEG Micon wind generators modeled as equivalents at each collector buses of the Phase II portion of the wind farm.

The Phase II turbine generator parameters were considered to be the same as of Phase I NEG Micon turbine parameters.

Collector Bus Number	100 % Case	80% Case	50% Case
Bus 1	17	17	17
Bus 2	15	17	14
Bus 3	14	15	-
Bus 4	14	-	-

Table 3 : Phase II Equivalent Generators with NEG Micon Turbines

The Customer provided parameters for a new 138 kV transmission line between Washita and Southwestern substations. The following transmission line parameters were used in the model:

Line resistance : 0.0129 ohms per 1000 ft
Line reactance : 1.372 ohms per 1000 ft

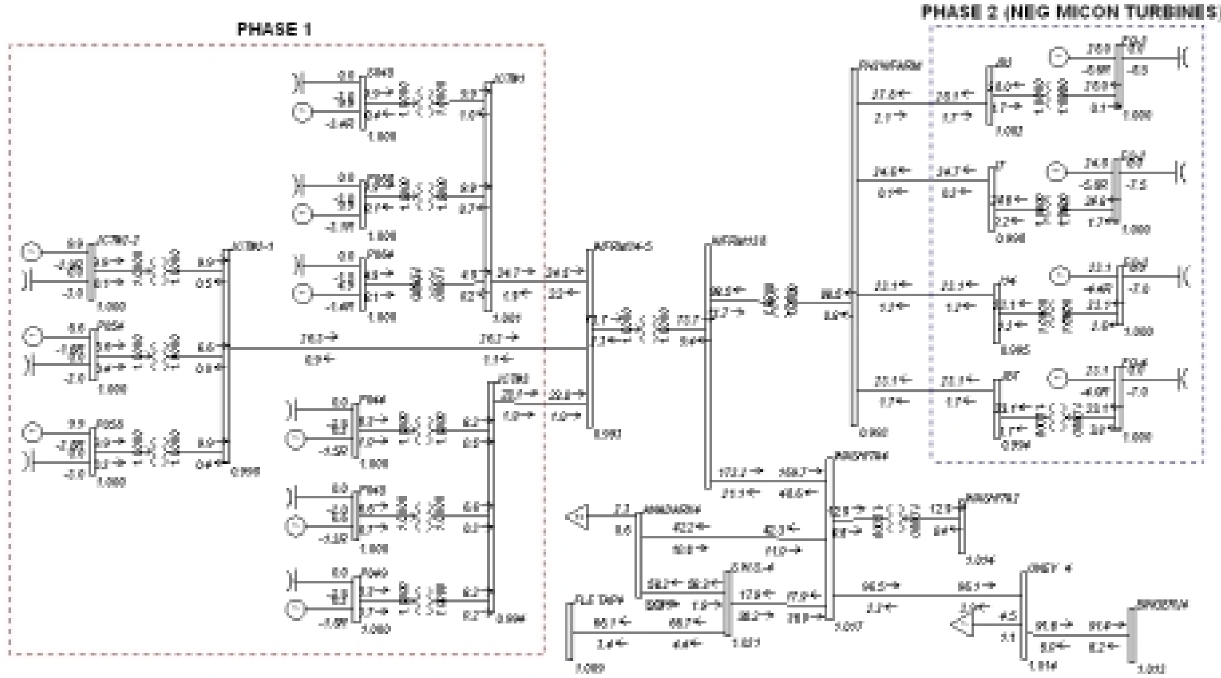
The Customer also provided the wind turbine feeder conductor types and lengths. Resistive values provided in their loss table and the inductive values from the Hendrix HQ200 standard tables for the specified conductors are shown in Table 4.

Conductor Size	Resistance (Ohms per 1000 ft)	Reactance (Ohms per 1000 ft)
1/0 AWG	0.212	0.055
4/0 AWG	0.107	0.049
1000 kcmil	0.028	0.037

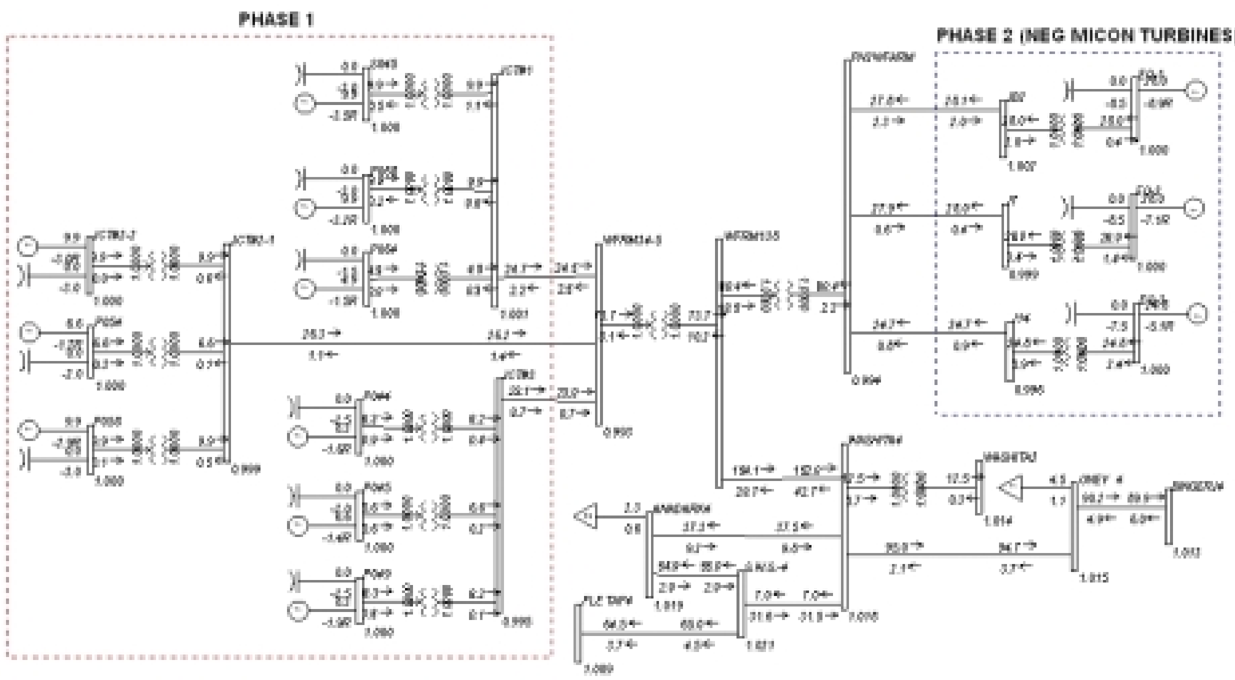
Table 4 : Conductor impedances

The study was performed using PTI's PSS/E program (version 28.4). This program is an industry-wide accepted power system simulation program. The wind generators were modeled as induction generators using the model CIMTR1 available in PSS/E.

The 100%, 80% and 50% base case power flow diagrams for the project GEN-2003-004 with NEG Micon turbines for the Phase II are shown in Figure 1.



100% BASE CASE POWER FLOW



80% BASE CASE POWER FLOW

Figure 1 : Base Case Power Flow Diagrams for Phase II with NEG Micon Turbines

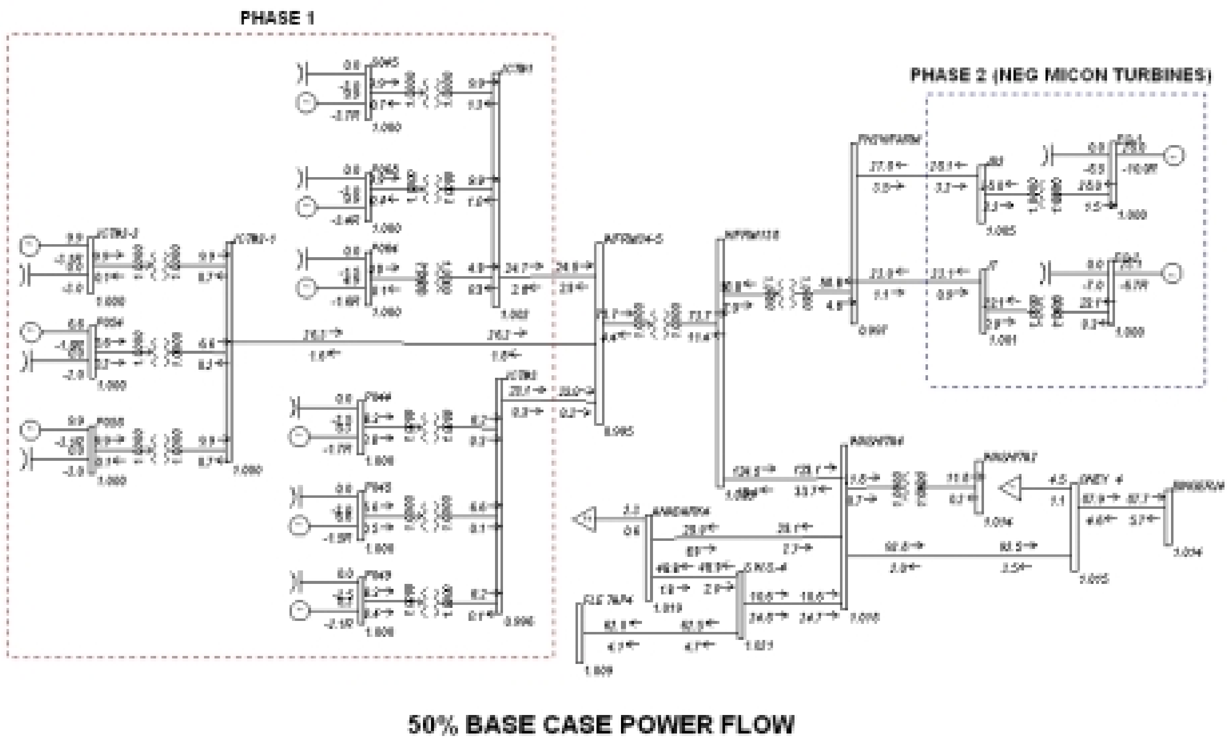


Figure 1 : Base Case Power Flow Diagrams for Phase II with NEG Micon Turbines (Cont'd)

5.2 STUDY ASSUMPTIONS

The following assumptions were made in the Study:

1. The wind speed over the entire wind farm was assumed to be uniform and constant during the study period.
2. Since the details of the wind turbine controllers were not provided in the data sheets, the mechanical input power of the wind generators were considered to be constant during the study period.

3. From the wind turbine data sheets the over/under frequency protection settings were used and are shown in Table 5. Typical values for under/over voltage protection were assumed.

Protective Function	Setting	Time Delay
Over Speed	+ 3%	3 seconds
Under Frequency	- 5%	3 seconds
Under Voltage	85%	0.4 seconds
Under Voltage	75%	0.08 seconds
Over Voltage	113.5%	0.2 seconds
Over Voltage	120%	0.08 seconds

Table 5 :NEG Micon Protective Functions and Settings

4. The generator transient reactance was considered to be 0.13 p.u. instead of 0.089 p.u. as indicated in the data sheet. With 0.13 p.u. as transient reactance for the induction generator model, the dynamic simulation did not settle down to the initial steady state value and the program terminated due to numerical instability. Minor adjustments to the transient reactance value were tried and a value of 0.089 p.u. was found to be successful.
5. The other generators in the WFEC control area were scaled down to accommodate the Phase I and Phase II generation. Table 6 indicates the generation dispatches levels for the three cases that were studied.

Scenario	Generation within WFEC
Without the Wind Farm	1180 MW
Phase I at full output and the Phase II at 100% output	1010 MW
Phase I at full output and the Phase II at 80% output	990 MW
Phase I at full output and the Phase II at 50% output	960 MW

Table 6 : WFEC Generation Dispatches with NEG Micon Turbines for Phase II

5.3 SIMULATION RESULTS

Initial simulation was carried out for 20 seconds without any disturbance to verify the numerical stability of the model and was confirmed to be stable.

The simulation results of all three cases (100%, 80% and 50%) indicated that there was no stability problem associated with the project GEN-2003-004 and all the synchronous generators' rotor angles settled down to steady state values. The bus voltages were found to recover to pre-fault values and hence no dynamic VAR support is required.

Table 7 provides the summary of the stability studies for the wind farm with NEG Micon turbines for the Phase II portion.

Fault Number	**100% Case**	**80% Case**	**50% Case**
FLT13PH	UV	UV	UV
FLT21PH	UV	UV	UV
FLT33PH	- -	- -	- -
FLT41PH	- -	- -	- -
FLT53PH	- -	- -	- -
FLT61PH	- -	- -	- -
FLT73PH	- -	- -	- -
FLT81PH	- -	- -	- -
FLT93PH	- -	- -	- -
FLT101PH	- -	- -	- -
FLT113PH	- -	- -	- -
FLT121PH	- -	- -	- -
FLT133PH	- -	- -	- -
FLT141PH	- -	- -	- -
FLT153PH	- -	- -	- -

UV : Tripped due to low voltage
OV : Tripped due to high voltage
UF : Tripped due to low frequency
OF : Tripped due to high frequency
S : Stability issues encountered
- - : Wind Farm did not trip

Table 7 : Stability Study Results Summary with NEG Micon turbines for Phase II

The Phase I and Phase II generators were found to be tripped, as expected, by the under voltage relays for scenarios FLT13PH and FLT21PH, which represented 3 phase and single phase faults on the Wind Farm – Washita 138 kV transmission line.

The Phase I and Phase II generators were found to stay connected to the grid for the remaining contingencies. The maximum over speed of the wind generators was about +1%.

As an illustration, Figure 2 shows the wind farm power outputs and the Washita 138 kV bus voltage for the contingency FLT13PH which is a three phase fault on the 138 kV transmission line between the wind farm and Washita switching station. Figure 3 shows the relative machine angles of Anadarko and Southwester Station machines with respect to Hugo machine.

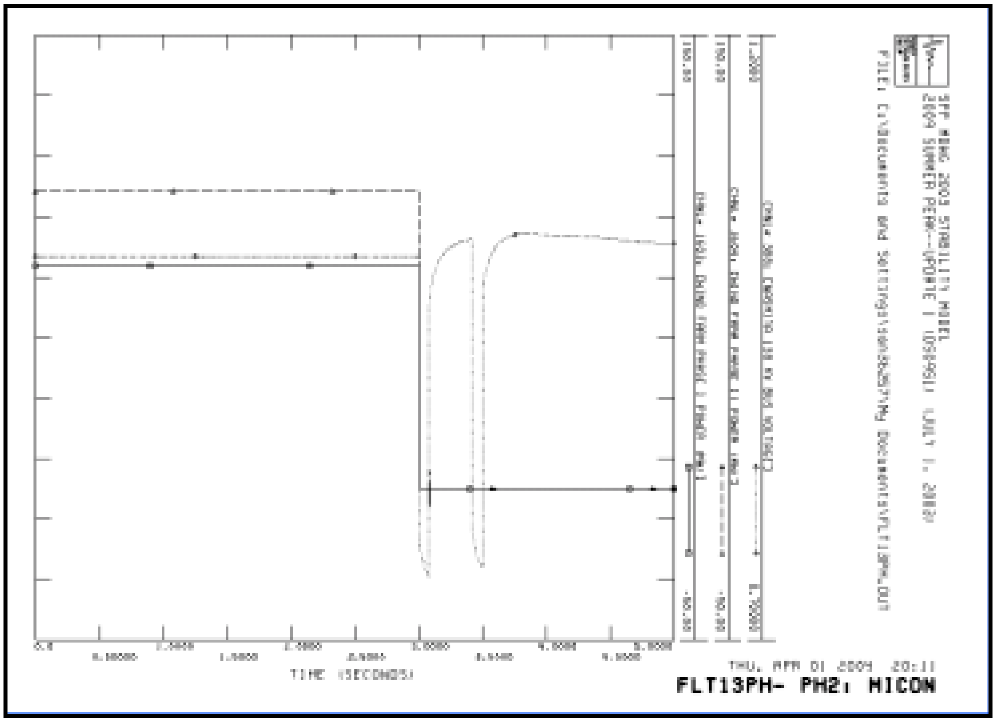


Figure 2 : Wind Farm output and Washita 138 kV Bus Voltage with Micon Turbines

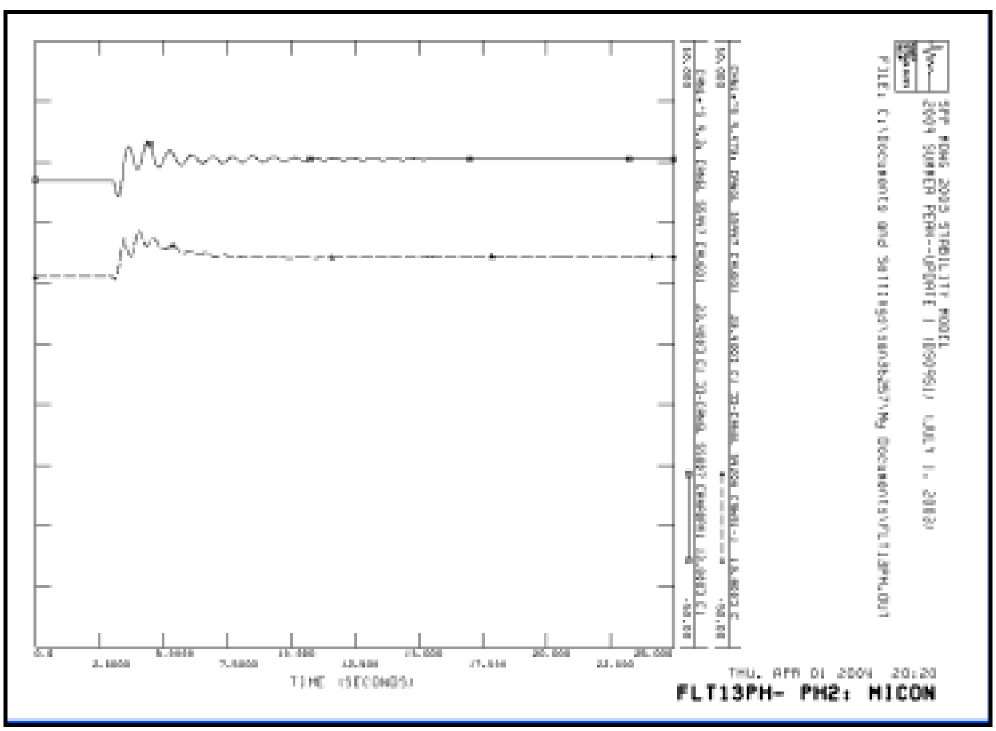


Figure 3 : Anadarko and Southwester Station machine angles with Micon Turbines

As an another illustration, Figure 4 shows the wind farm output and the Washita 138 kV bus voltage for the contingency FLT53PH which is a three phase fault on Southwester Station – Anadarko 138 kV line. It demonstrates that both Phase I and Phase II portion of the wind turbines stay connected to this grid fault.

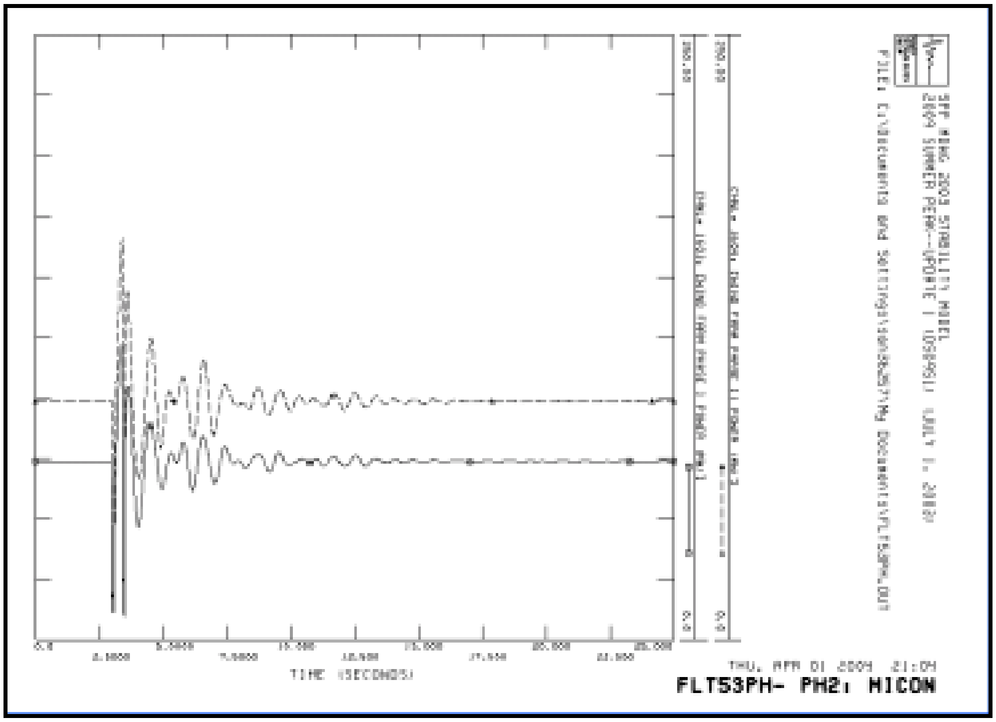


Figure 4: Wind Farm Output for FLT53PH with Micon Turbines

6. PHASE II WITH GE 1.5 MW TURBINES

6.1 SIMULATION MODEL

The customer requested that the System Impact Study for Phase II of the project include an option to use GE wind turbines. The GE turbines are a three phase double fed induction generator. The following are the main electrical parameters of the GE 1.5 MW wind turbine.

Rated Power	: 1.5 MW
Apparent Power	: 1,670 kVA
Maximum Reactive Power Output	: 290 kVAR
Maximum Reactive Power Consumption	: 436 kVAR

The models of the Phase I and Phase II equipment such as generators, transformers and cables were added to the base case for the purpose of this study. The Operational Diagram for the Phase II portion of the wind farm was based on the number of collector circuits shown on the Customer provided single line diagram.

Table 8 provides the number of GE 1.5 MW wind generators modeled as equivalents at each collector buses of the Phase II portion of the wind farm.

Collector Bus Number	100 % Case	80% Case	50% Case
Bus 1	16	18	17
Bus 2	17	18	17
Bus 3	17	18	-
Bus 4	17	-	-

Table 8 : Phase II Equivalent Generators with GE 1.5 MW Turbines

The Customer provided parameters for a new 138 kV transmission line between Washita and Southwestern substations. The following transmission line parameters were used in the model:

Line resistance : 0.0129 ohms per 1000 ft
Line reactance : 1.372 ohms per 1000 ft

The Customer also provided the wind turbine feeder conductor types and lengths. Resistive values provided in their loss table and the inductive values from the Hendrix HQ200 standard tables for the specified conductors are shown IN Table 9. Line charging is negligible for the length of cables considered in the study and so was not included.

Conductor Size	Resistance (Ohms per 1000 ft)	Reactance (Ohms per 1000 ft)
1/0 AWG	0.212	0.055
4/0 AWG	0.107	0.049
1000 kcmil	0.028	0.037

Table 9: Conductor Impedances

The Phase II wind farm was modeled using the GE wind turbine model available in PSS/E. The effects of rotor current control and the turbine pitch control were also modeled. The GE data used in the study is as noted in Table 10.

The 100%, 80% and 50% base case power flow diagrams for the project GEN-2003-004 with GE 1.5 MW turbines for the Phase II are shown in Figure 5.

Description	Value
Stator resistance, Ra	0.00706 pu
Stator inductance, La	0.1714 pu
Mutual inductance, Lm	2.904 pu
Rotor resistance	0.005 pu
Rotor inductance	0.1563 pu
Drive train inertia	0.64 sec
Shaft damping	0.73 pu
Shaft stiffness	0.6286 pu
Turbine rotor inertia	4.0 sec
Number of generator pole pairs	3
Gear box ratio	72.0

Table 10 : GE 1.5 MW Wind Turbine Generator Parameters

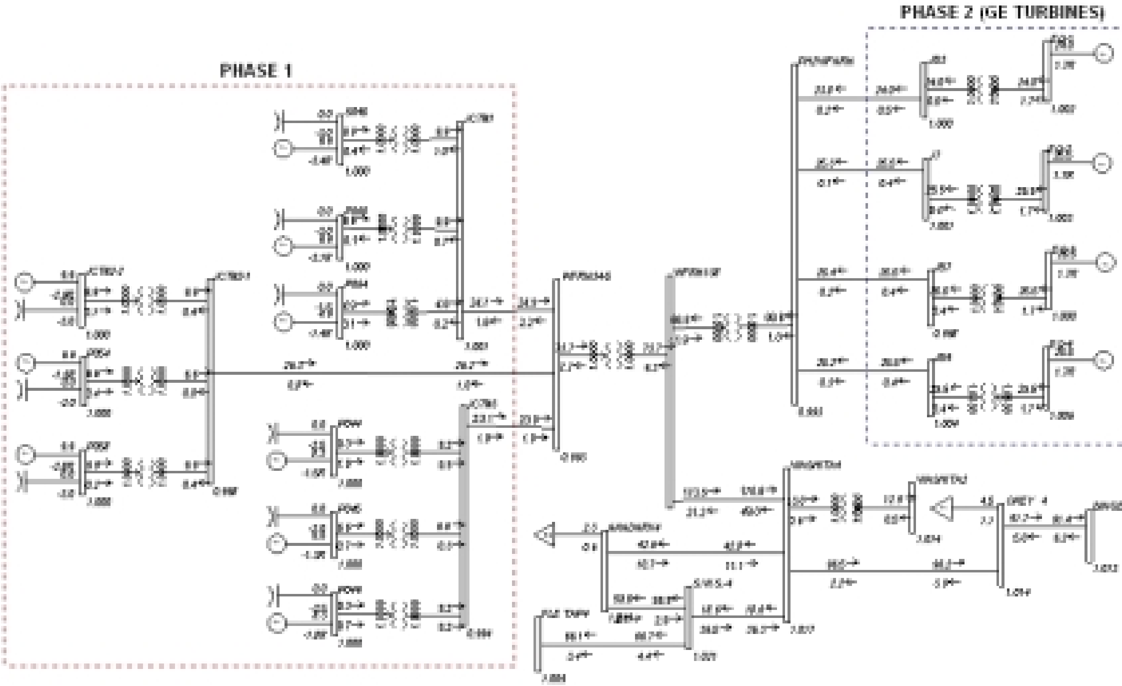
6.2 STUDY ASSUMPTIONS

The following assumptions were made in the Study:

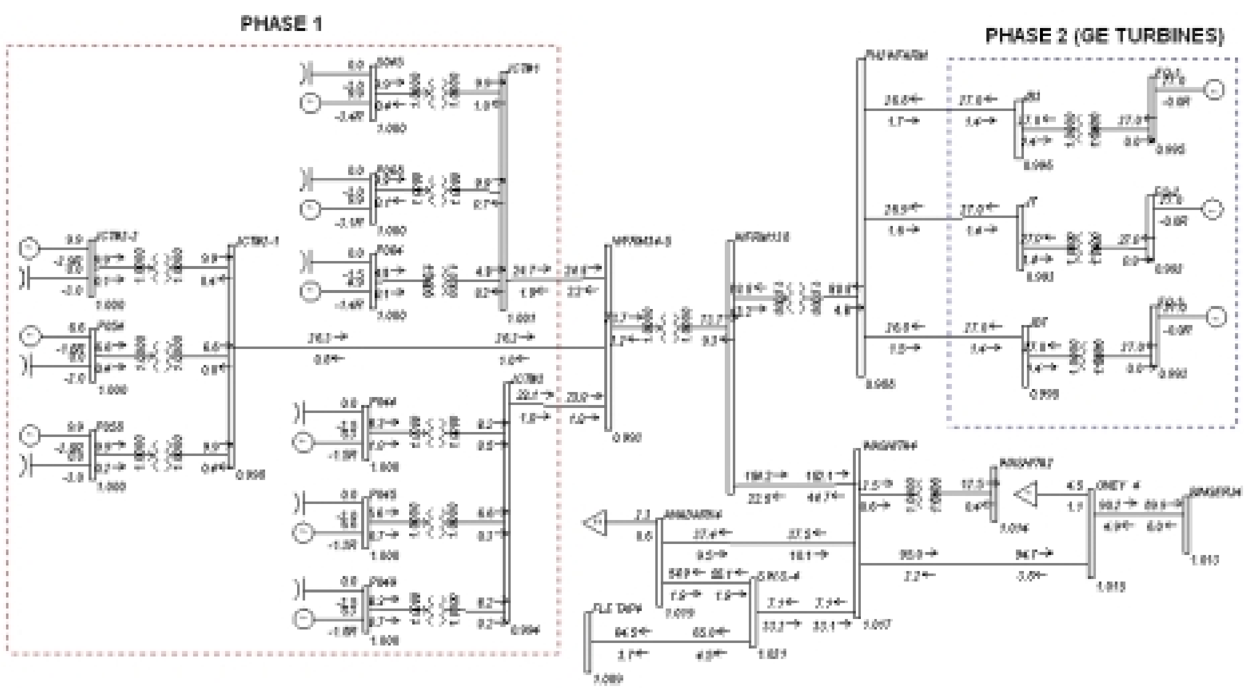
1. The wind speed over the entire wind farm was assumed to be uniform and constant during the study period.
2. The turbine control models available within PSS/E such as CGECN2, TWIND1 and TGPTCH were used with their default values.
3. From the wind turbine data sheets the protection settings were used as and are shown in Table 11.
4. The other generators in the WFEC control area were scaled down to accommodate the Phase I and Phase II generation as indicated in Table 12.

Scenario	Generation within WFEC
Without the Wind Farm	1180 MW
Phase I at full output and the Phase II at 100% output	1010 MW
Phase I at full output and the Phase II at 80% output	990 MW
Phase I at full output and the Phase II at 50% output	960 MW

Table 12 : WFEC Dispatches



100% BASE CASE POWER FLOW



80% BASE CASE POWER FLOW

Figure 5 : Base Case Power Flow Diagrams for Phase II with GE 1.5 MW Turbines

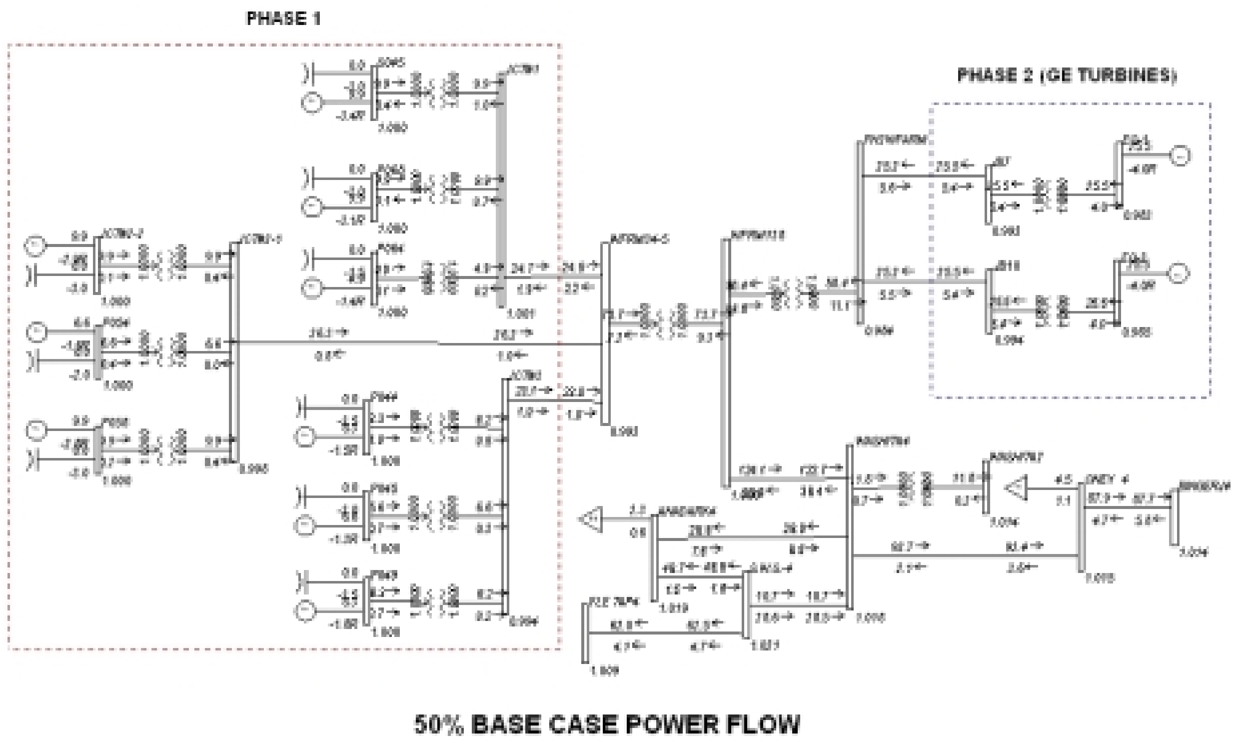


Figure 5 : Base Case Power Flow Diagrams for Phase II with GE 1.5 MW Turbines (Cont'd)

Protective Function	Protection Setting	Time Delay
Over Frequency	61.5 Hz	30 seconds
Over Frequency	61.7 Hz	0.02 seconds
Under Frequency	56.5 Hz	0.02 seconds
Under Frequency	56.9 Hz	0.12 seconds
Under Frequency	57.4 Hz	0.75 seconds
Under Frequency	57.9 Hz	7.5 seconds
Under Frequency	58.5 Hz	30 seconds
Under Voltage	30%	0.02 seconds
Under Voltage	70%	0.1 seconds
Under Voltage	80%	10.0 seconds
Over Voltage	110%	0.2 seconds
Over Voltage	115%	0.1 seconds
Over Voltage	130%	0.02 seconds

Table 11 : Protective Functions and Settings for GE 1.5 MW Turbines

6.3 SIMULATION RESULTS

Initial simulation was carried out for 20 seconds without any disturbance to verify the numerical stability of the model and was confirmed to be stable.

Table 13 provides the summary of the stability studies with GE 1.5 MW turbines for Phase II.

Fault Number	100% Case	80% Case	50% Case
FLT13PH	UV	UV	UV
FLT21PH	UV	UV	UV
FLT33PH	- -	- -	- -
FLT41PH	- -	- -	- -
FLT53PH	UV	UV	UV
FLT61PH	- -	- -	- -
FLT73PH	- -	- -	- -
FLT81PH	- -	- -	- -
FLT93PH	- -	- -	- -
FLT101PH	- -	- -	- -
FLT113PH	- -	- -	- -
FLT121PH	- -	- -	- -
FLT133PH	- -	- -	- -
FLT141PH	- -	- -	- -
FLT153PH	UV	UV	UV

UV : Tripped due to low voltage
OV : Tripped due to high voltage
UF : Tripped due to low frequency
OF : Tripped due to high frequency
S : Stability issues encountered
- - : Wind Farm did not trip

Table 13 : Stability Study Results Summary with GE 1.5 MW turbines for Phase II

The Phase I and Phase II generators were found to be tripped, as expected, by the under voltage relays for scenarios FLT13PH and FLT21PH, which represented 3 phase and single phase faults on the Wind Farm – Washita 138 kV transmission line.

The phase II generators were found to be tripped also for the following faults:

- FLT53PH : Three phase fault on Southwester Station – Anadarko 138 kV line, closer to Southwester Station

- FLT153PH: Three phase fault on Washita-Southwester Station 138 kV line, closer to Washita

The Phase I and Phase II generators were found to stay connected to the grid for the remaining contingencies. The voltages at the Phase II wind generator terminals were found to be lower than 0.7 p.u for more than 0.1 seconds for the above two contingencies and hence the generators were found to be tripped by the under voltage relays as illustrated in Figure 6.

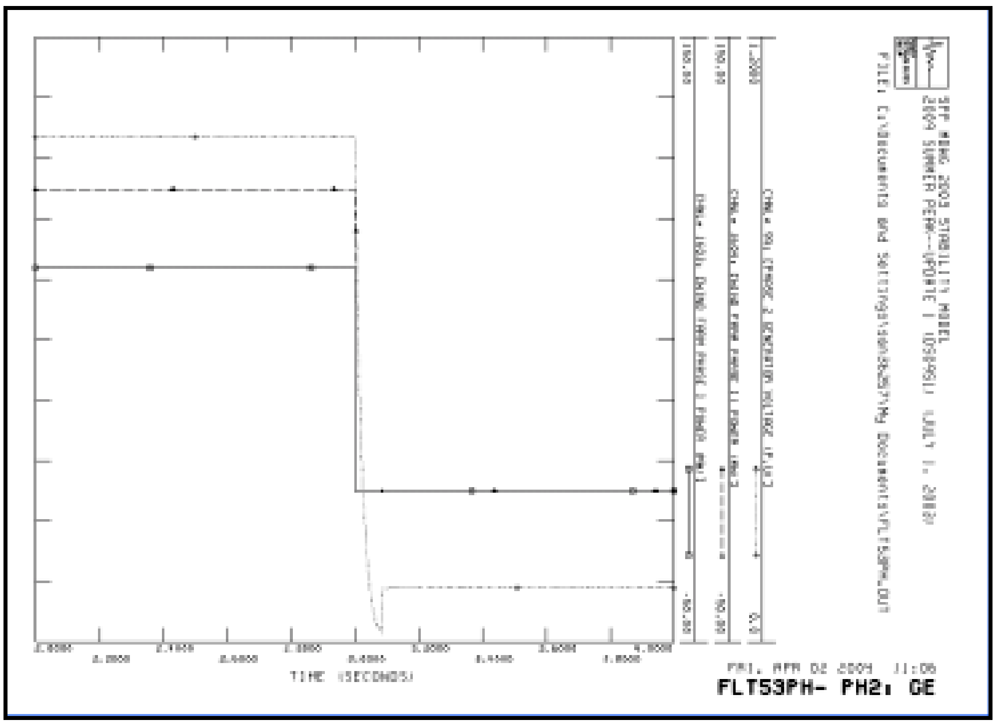


Figure 6 : Wind Farm Output and Phase II Generator Voltage with GE Turbine

It is understood that special control and protection packages are available for the GE 1.5 MW wind turbines as an optional feature which would enable the turbine generators to ride through the low voltages up to 15% for 500 mS. Simulations were carried out by considering this special protection scheme, instead of the standard protection scheme listed in Section 7.2, and the wind generators were found to ride through the low voltages during the contingencies FLT53PH and FLT153PH as illustrated in Figure 7 and Figure 8.

The simulation results of all three cases (100%, 80% and 50%) indicated that there was no stability problem associated with the project GEN-2003-004 and all the synchronous generators' rotor angles settled down to steady state values. The bus voltages were found to recover to pre-fault values and hence no dynamic VAR support is required.

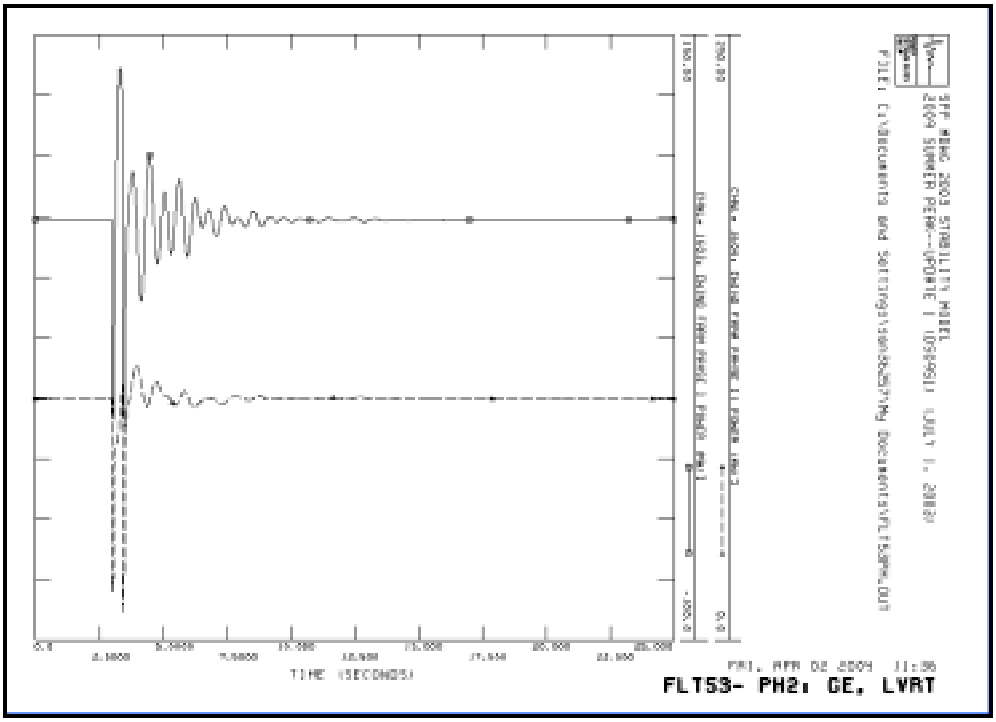


Figure 7 : Wind Farm output power With Low Voltage Ride Through Capability

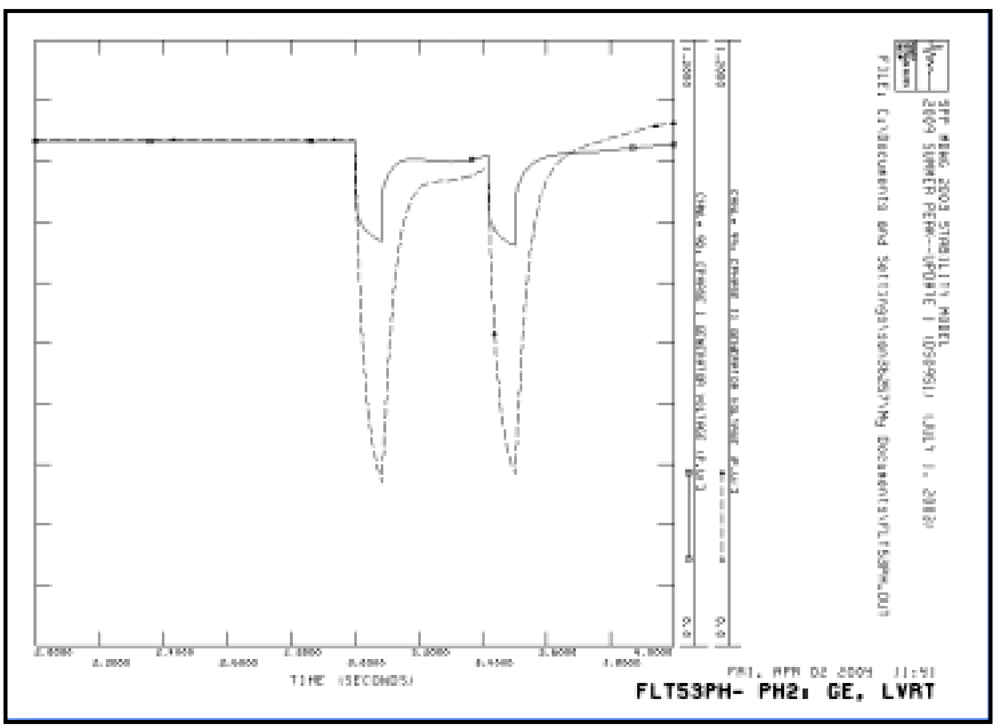


Figure 8 : Phase I and II generator voltages with Low Voltage Ride Through Capability

8. COST ESTIMATE

The estimated cost of the new transmission line is shown in Table 14.

No.	Description	Estimated Cost (+/- 15%)
1	New 3 mile 138 kV transmission line between Washita and Southwestern Station	$ 1,200,000
2	Modifications at Southwestern Station, i.e adding an extra bay to the existing substation	$ 1,200,000
	Total	$ 2,400,000

Table 14 : Estimated Cost of the new Washita – Southwestern Station 138 kV line

9. SUMMARY

A transient stability analysis was conducted for the SPP Interconnection Generation Queue Position GEN-2003-004 with its output at 100 MW, 80 MW and 50 MW. The study considered NEG Micon and GE 1.5 MW turbines as possible options. The study has not indicated any angular or voltage instability problem for the contingencies analyzed in both the options. The study has also indicated that the GE 1.5 MW turbines will have to be provided with the low voltage ride through facility (15% for 500 ms) in order to continue the operation during the grid faults.

Based on the under voltage tripping identified in the study cases FLT53PH and FLT153PH, the Interconnection Customer shall discuss with GE, the wind turbine manufacturer, the new control and protection packages available for the GE 1.5 MW wind turbines which would enable the turbine generators to ride through low voltages up to 15% for 500 Ms. If this modification is not available the Interconnection Customer shall consider the additional risk implications of wind farm outages that this wind turbine under voltage control scheme may cause to the wind farm.

Disclaimer

If any previously queued projects that were included in this study drop out, then this System Impact Study may have to be revised to determine the impacts of this Interconnection Customer's project on WFEC transmission facilities. Since this is also a preliminary System Impact Study, not all previously queued projects were assumed to be in service in this System Impact Study. If any of those projects are constructed, then this System Impact Study may have to be revised to determine the impacts of this Interconnection Customer's project on WFEC transmission facilities. In accordance with

FERC and SPP procedures, the study cost for restudy shall be borne by the Interconnection Customer.