Southwest Power Pool

Impact Study for Generation Interconnection Request GEN – 2003 – 004

SPP Coordinated Planning
(#GEN-2003-004)

January 2005

Summary

Black & Veatch (B&V) performed the following study at the request of the Southwest Power Pool (SPP) for Generation Interconnection request Gen-2003-004. 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.

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 one different wind turbine machine and three MW levels.

Due to the under voltage trips noted in the stability study results in table 8 the Customer shall purchase the Advanced Grid Option 4 (AGO4) protection package in order to continue operation during grid faults.

IMPACT STUDY FOR SPP GENERATION

QUEUE POSITION GEN-2003-004

(REVISED STUDY)

SOUTHWEST POWER POOL (SPP)

January 20, 2005

By

BLACK & VEATCH

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EXECUTIVE SUMMARY

A revised 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 Vestas V80-1.8 MW turbines.

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 Vestas V80-1.8 MW wind generators were modeled using the induction generator model and the Vestas 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.

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 Vestas V80-1.8 MW turbines will have to be provided with the optional AGO4 voltage ride through scheme in order to continue the operation during the grid faults.

Based on the study results, the Customer shall discuss with Vestas, the turbine manufacturer, the new control and protection packages available for the Vestas V80-1.8 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. As noted in the original study the estimated cost of this new transmission line with the upgrade for Southwest Station is about $2,400,000 has not changed.

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 revised 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 (WFEC) 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.

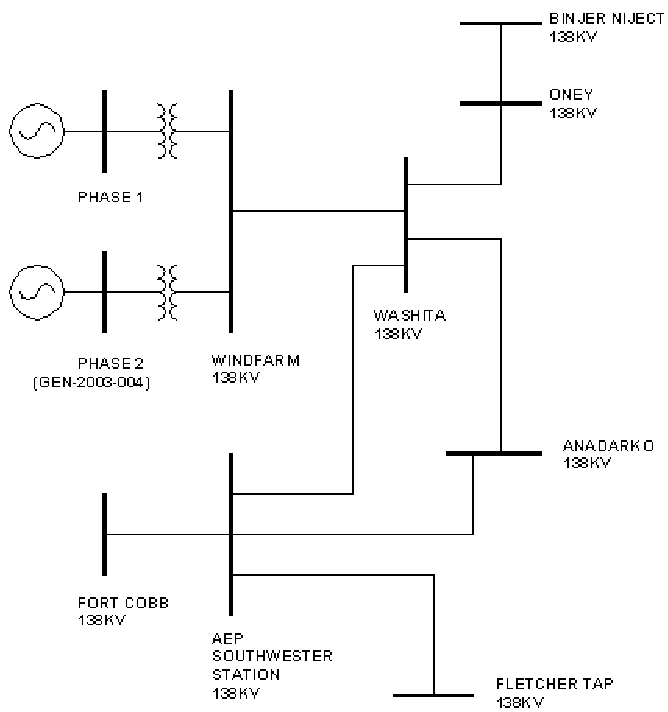

Figure 1: System One Line Diagram near GEN-2003-004

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 contain Vestas V80-1.8 MW turbines.

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 periodic 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 Southwestern Station – Anadarko 138 kV line, closer to Southwestern Station.
FLT61PH	Single phase fault on Southwestern Station – Anadarko 138 kV line, closer to Southwestern Station.
FLT73PH	Three phase fault on Southwestern Station – Fort Cobb 138 kV line, closer to Fort Cobb.
FLT81PH	Single phase fault on Southwestern 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 – Southwestern Station 138 kV line, closer to Washita.
FLT161PH	Single phase fault on Washita – Southwestern 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 VESTAS V80-1.8 MW TURBINES

5.1 SIMULATION MODEL

The customer requested that the System Impact Study for Phase II of the project include Vestas V80-1.8 MW wind turbines. The Vestas V80-1.8 MW turbines are a three phase induction generators with a proprietary rotor resistance control called “optislip control”. The following are the main electrical parameters of the Vestas V80-1.8 MW wind turbine.

Rated Power	: 1.8 MW
Voltage	: 690 V
Power Factor Correction	: 864 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 data.

Table 3 provides the number of Vestas V80-1.8 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	13	11	9
Bus 2	14	12	10
Bus 3	13	11	9
Bus 4	14	11	-
Bus 5	2	-	-

Table 3 : Phase II Equivalent Generators with Vestas V80-1.8 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 4. 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 4: Conductor Impedances

The Phase II wind farm was modeled using the Vestas V80-1.8 MW wind turbine model available in PSS/E. The effects of rotor current control and the turbine pitch control were also modeled. The Vestas machine data used in the study is as noted in Table 5.

The 100%, 80% and 50% base case power flow diagrams for the project GEN-2003-004 with Vestas V80-1.8 MW turbines for the Phase II are shown in Figure 2.

Description	Value
Stator resistance, Ra	0.0049 pu
Stator inductance, La	0.126 pu
Mutual inductance, Lm	6.8399 pu
Rotor resistance	0.0887 pu
Rotor inductance	0.1808 pu
Generator inertia	0.644 sec
Damping factor	0.0 pu
Shaft stiffness	0.92 pu
Turbine rotor inertia	0.1 sec
Number of generator pole pairs	2
Gear box ratio	120.6

Table 5: Vestas V80-1.8 MW Wind Turbine Generator Parameters

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. 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 standard protection settings were used as and are shown in Table 7.
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 6.

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 Dispatches

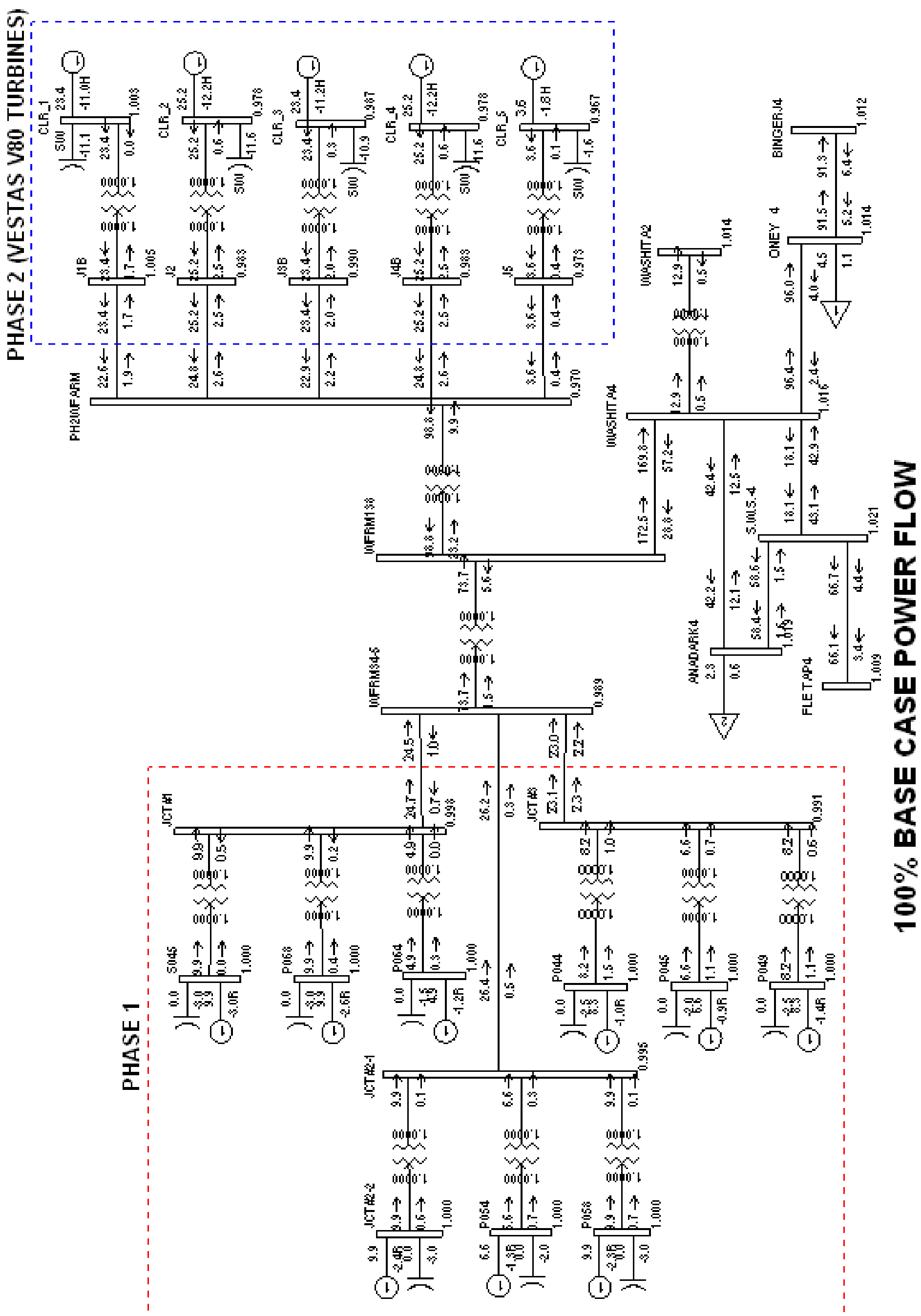

Figure 2: Base Case Power Flow Diagrams for Phase II with Vestas V80-1.8 MW Turbines

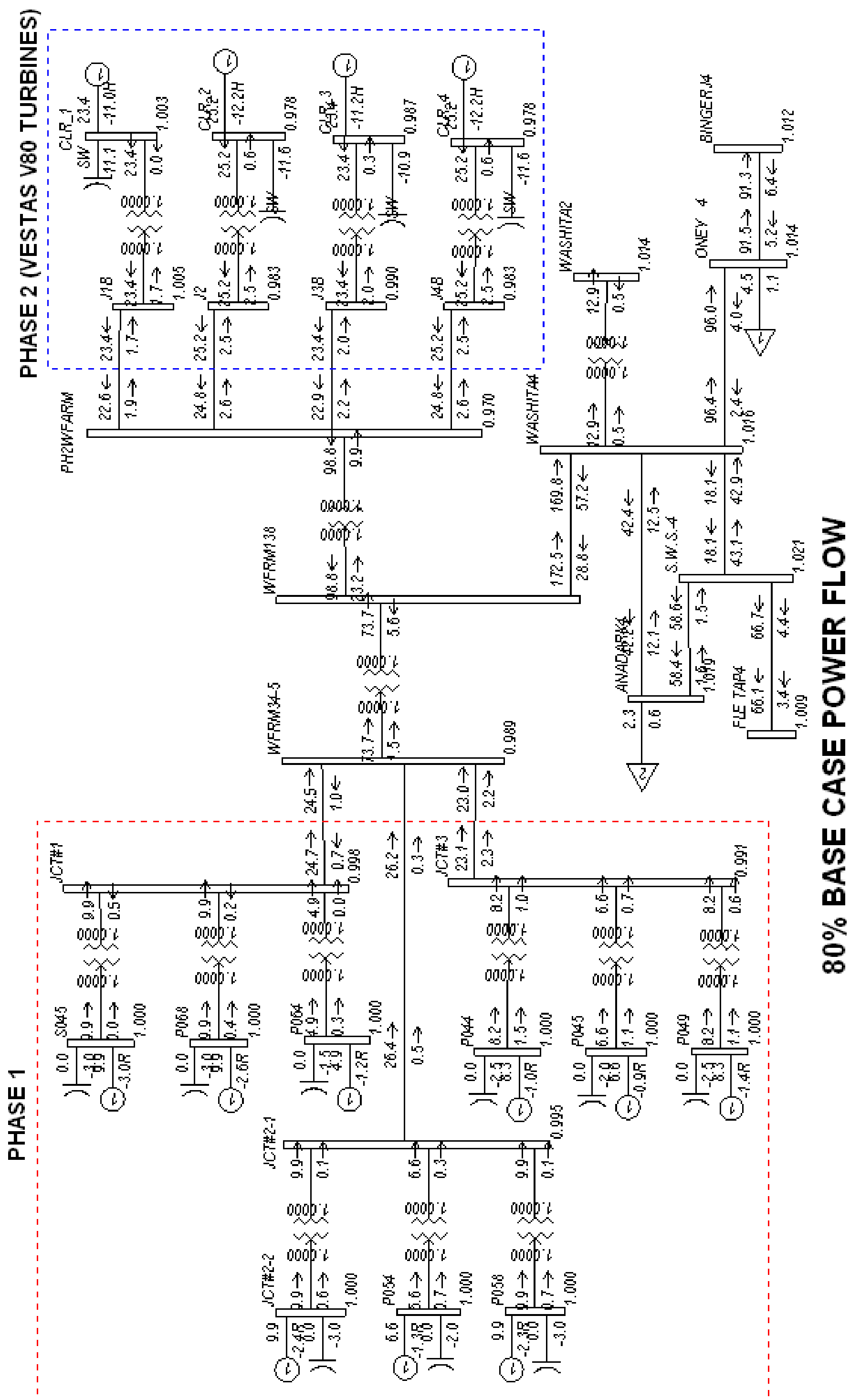

Figure 2: Base Case Power Flow Diagrams for Phase II with Vestas V80-1.8 MW Turbines (Cont'd)

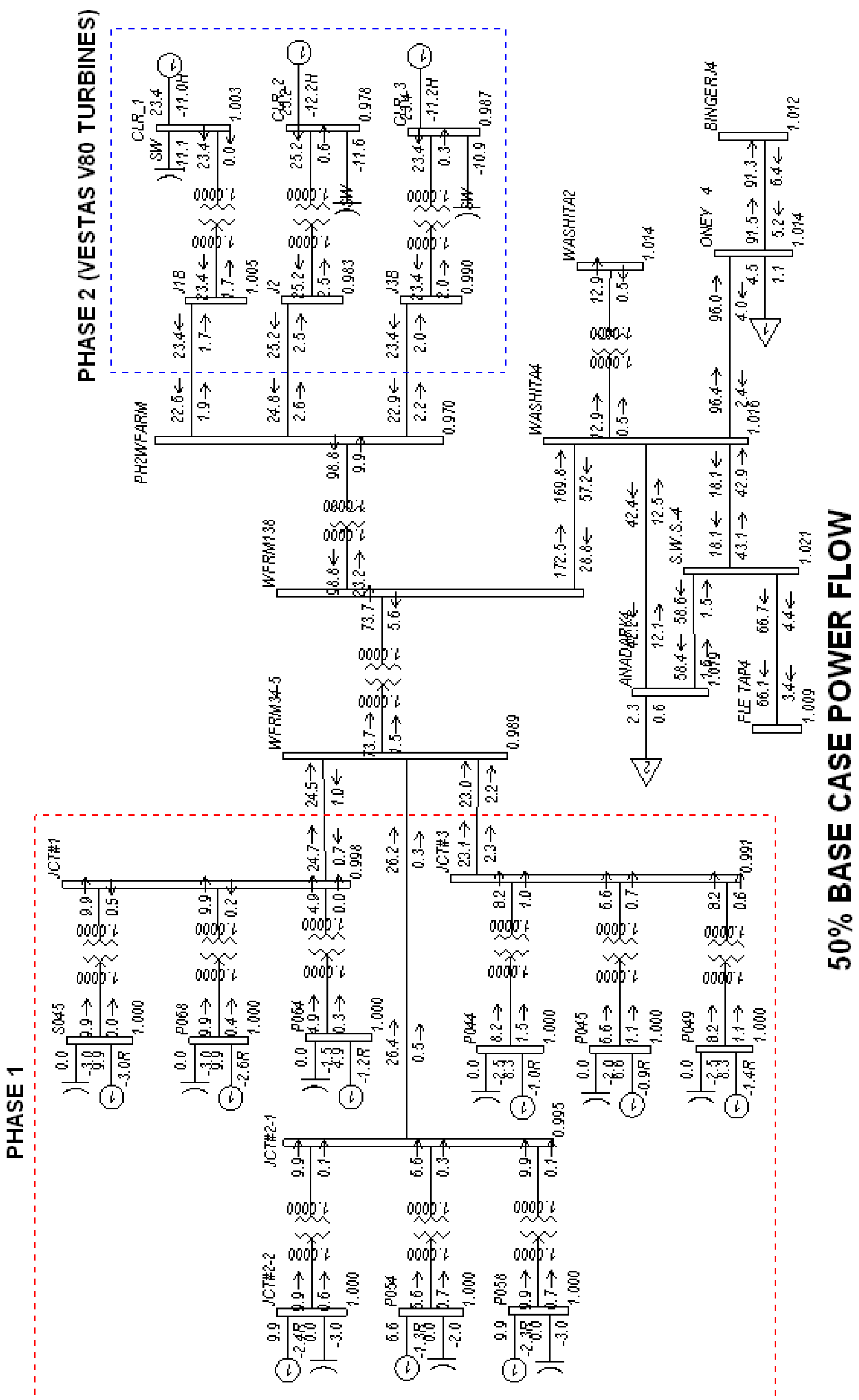

Figure 2: Base Case Power Flow Diagrams for Phase II with Vestas V80-1.8 MW Turbines (Cont'd)

Protective Function	Protection Setting	Time Delay
Over Frequency	62.0 Hz	0.2 seconds
Under Frequency	57.0 Hz	0.2 seconds
Under Voltage	75%	0.08 seconds
Under Voltage	85%	0.4 seconds
Under Voltage	94%	60.0 seconds
Over Voltage	110%	60.0 seconds
Over Voltage	113.5%	0.2 seconds
Over Voltage	120%	0.08 seconds

Table 7: Standard Protective Functions and Settings for Vestas V80-1.8 MW Turbines

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.

Table 8 provides the summary of the stability studies with Vestas V80-1.8 MW turbines with standard protection package for Phase II.

Table 8: Stability Study Results for Phase II with standard Vestas V80-1.8 MW package

Fault Number	100% Case	80% Case	50% Case
FLT13PH	UV	UV	UV
FLT21PH	UV	UV	UV
FLT33PH	UV	UV	UV
FLT41PH	- -	- -	- -
FLT53PH	UV	UV	UV
FLT61PH	- -	- -	- -
FLT73PH	UV	UV	UV
FLT81PH	- -	- -	- -
FLT93PH	- -	- -	- -
FLT101PH	- -	- -	- -
FLT113PH	UV	UV	UV
FLT121PH	- -	- -	- -
FLT133PH	- -	- -	- -
FLT141PH	- -	- -	- -
FLT153PH	UV	UV	UV
FLT161PH	- -	- -	- -

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

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:

- FLT33PH: Three phase fault on Washita – Anadarko 138 kV line, closer to Anadarko
- FLT53PH: Three phase fault on Southwestern Station – Anadarko 138 kV line, closer to Southwestern Station
- FLT73PH: Three phase fault on Southwestern Station – Fort Cobb 138 kV line, closer to Fort Cobb
- FLT113: Three phase fault on Washita – Oney 138 kV line, closer to Oney
- FLT153: Three phase fault on Washita – Southwestern 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 0.75 p.u for more than 0.08 seconds for the above contingencies and hence the generators were found to be tripped by the under voltage relays as illustrated in Figure 3.

It is understood that a special control and protection package called Advanced Grid Option 4 (AGO4) is available for the Vestas V80-1.8 MW wind turbines as an optional feature which would enable the turbine generators to ride through the low voltages. The voltage protection settings of AGO4 option are shown in Table 9.

Protective Function	**Protection Setting**	**Time Delay**
Under Voltage	50%	0.2 seconds
Under Voltage	75%	0.8 seconds
Under Voltage	80%	2.0 seconds
Under Voltage	90%	300.0 seconds
Over Voltage	115%	30.0 seconds
Over Voltage	120%	2.0 seconds
Over Voltage	125%	0.08 seconds

Table 9: AGO4 Protective Functions and Settings for Vestas V80-1.8 MW Turbines

Simulations were carried out by considering AGO4 special protection scheme, instead of the standard protection scheme listed in Section 5.2, and the wind generators were found to ride through the low voltages during all the contingencies studied. A sample plot of the system response with the AGO4 protection package is shown in Figure 4.

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.

6. COST ESTIMATE

The estimated cost of the new transmission line is shown in Table 10.

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

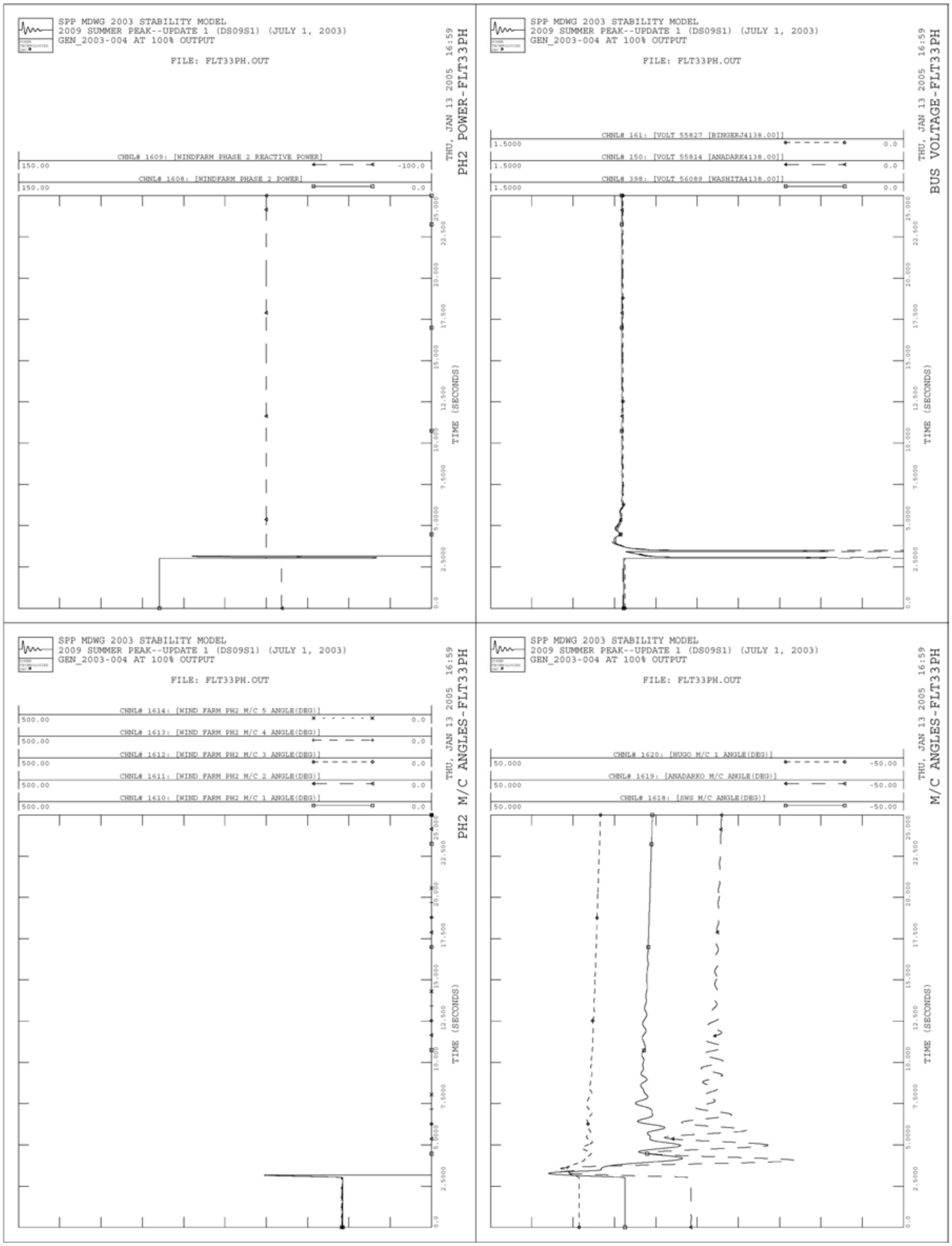

Figure 3: System Response with the standard protection package

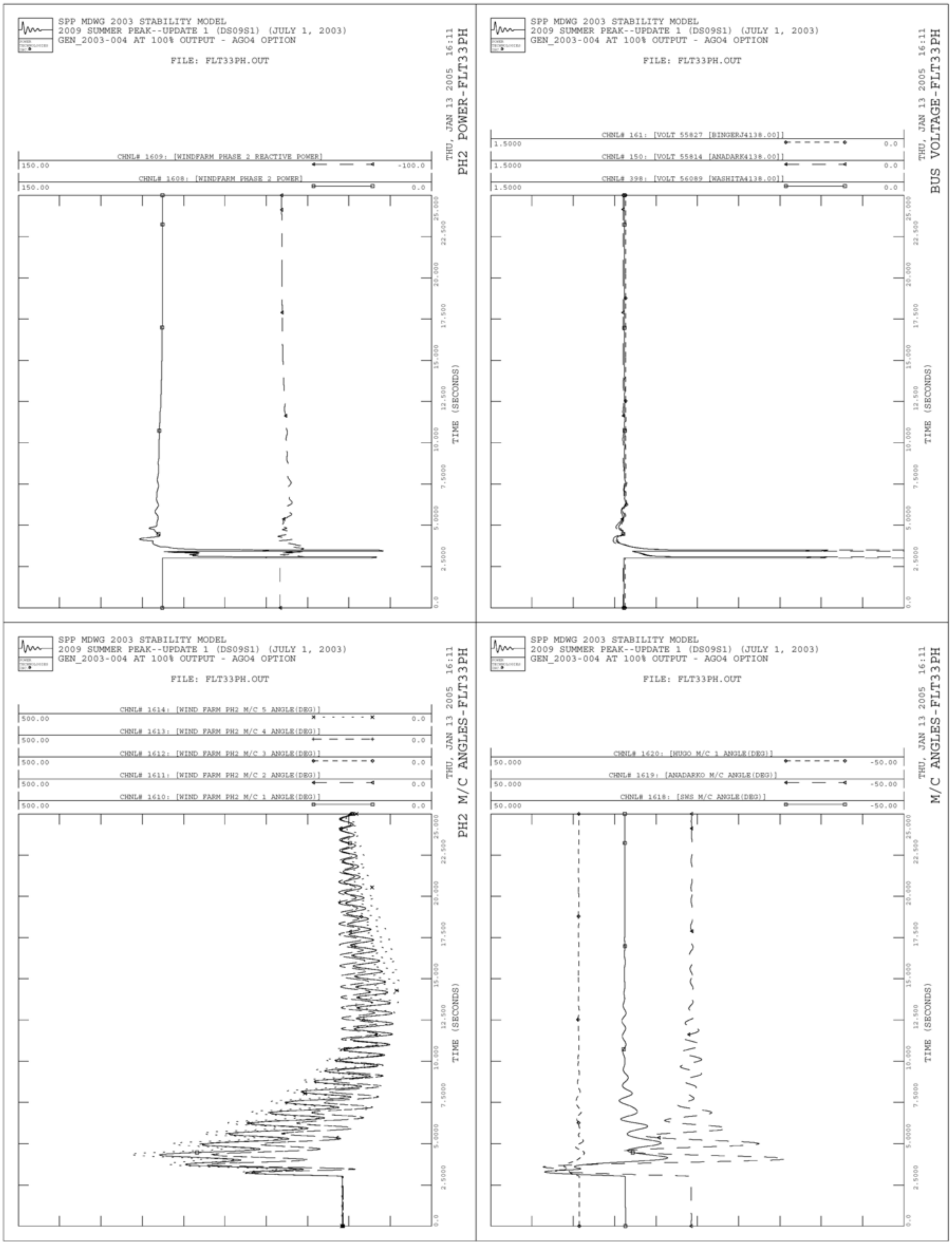

Figure 4: System Response with AGO4 Option

7. SUMMARY

A revised 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 Vestas V80-1.8 MW turbines for the wind farm. 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 Vestas V80-1.8 MW turbines will have to be provided with the Advanced Grid Option 4 (AGO4) protection package in order to continue the operation during the grid faults.

Based on the under voltage tripping identified in the study, the Interconnection Customer shall discuss with Vestas, the wind turbine manufacturer, the optional AGO4 control and protection packages available for the Vestas V80-1.8 MW wind turbines which would enable the turbine generators to ride through low voltages. 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.