Southwest Power Pool

Impact Re-Study #2 For Generation Interconnection Request GEN-2008-098 & GEN-2010-003

SPP Generation Interconnection

(GEN-2008-098 & GEN-2010-003)

April 2012

Executive Summary

This report contains the findings of a second restudy of GEN-2008-098 and GEN-2010-003 interconnection requests. Both projects are owned by the same customer and each project will generate 100.8MW using the Vestas V100 wind turbine generators. The two projects are collocated and share the same 34.5/345kV substation transformer and transmission line to the Point of Interconnection (POI).

The initial impact study for these two projects is found in the SPP Definitive Interconnection System Impact Study 2010-001 (DISIS-2010-001), dated July 2010. The DISIS-2010-001 study revealed some oscillatory issues related to the customer's projects and the Wolf Creek facility. The Transmission Owner requested a restudy in order that a more detailed analysis be performed for the interconnection of both of the wind generating facilities into the Wolf Creek – LaCygne 345kV transmission line. The Impact Restudy for Generation Interconnection Request GEN-2008-098 and GEN-2010-003 (dated January 2012) reports the findings of the study. The Vestas V90 1.8MW wind turbines were used in both the DISIS and the first restudy.

Subsequent to the first restudy the customer has requested a change in wind turbine generator model from the Vestas V90 1.8MW machine to the Vestas V100 1.8MW machine. The customer has requested a second restudy to determine the effects on the network due to using the Vestas V100 1.8MW wind turbine generators.

At present the Transmission Owner has a Transmission Operations Directive (TOD) that adjusts the Wolf Creek generation following an outage of any one of the three 345kV transmission lines that serve Wolf Creek. The purpose of the TOD is to mitigate the potential of oscillatory issues if a second 345kV line serving Wolf Creek were to be removed from service. This is accomplished by reducing the Wolf Creek generation to 800MW. The attached study shows that with the addition of GEN-2008-098/GEN-2010-003 projects, the maximum allowable generation during periods when a 345kV line is out of service remains at 800MW. Therefore, during the conditions for which the TOD applies (i.e. the outage of the lines listed below) the output of GEN-2008-098 and GEN-2010-003 must be reduced to 0MW. The lines whose outage triggers this directive are

- Wolf Creek – LaCygne 345kV line
    - o After the interconnection of the study projects, the line segment between the study projects and LaCygne
- Wolf Creek – Benton 345kV line
- Wolf Creek – Rose Hill 345kV line

With the assumptions and operation requirements described above, study projects GEN-2008-098 and GEN-2010-003 utilizing the Vestas V100 1.8MW wind turbine generator should be able to interconnect without causing any stability problems on the SPP transmission grid. In addition, consistent with Order #661A, the facility will be required to maintain a 95% lagging (providing vars) and 95% leading (absorbing vars) power factor at the point of interconnection.

Nothing in this study should be construed as a guarantee of transmission service. If the customer wishes to sell power from the facility, a separate request for transmission service shall be requested on Southwest Power Pool's OASIS by the Customer.

SPP GEN-2008-098 and GEN-2010-003 Impact Restudy

Final Report for

Southwest Power Pool

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0. Certification

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the Laws of the State of **Kansas**.

William Quaintance
Kansas License Number: 20756

Excel Engineering, Inc.
Kansas License Number: 1611

1. Background and Scope

The GEN-2008-098 and GEN-2010-003 Impact Restudy is a generation interconnection study performed by Excel Engineering, Inc. for its non-affiliated client, Southwest Power Pool (SPP). Its purpose is to study the impacts of interconnecting the project shown in Table 1-1. The in-service date assumed for the generation addition was 2011.

Table 1-1. Interconnection Requests Evaluated in this Study

Request	Size (MW)	Wind Turbine Model	Point of Interconnection	POI Bus	Gen Buses
GEN-2008-098	100.8	Vestas V100 VCSS 1.8MW	Wolf Creek – LaCygne 345kV	572090	572094
GEN-2010-003	100.8	Vestas V100 VCSS 1.8MW	Gen-2008-098 addition	572090	577200

Other projects that are concurrent with the study projects are shown in Table 1-2.

Table 1-2. Other Concurrent Projects

Request	Size	Wind Turbine Model	Point of Interconnection	POI Bus	Gen Buses
GEN-2008-071	76.8	GE 1.6MW	Newkirk 138kV	514759	577000
GEN-2010-005	300	Clipper C96 2.5MW	Gen-2007-025 345kV	532781	576100 576110

The prior-queued requests shown in Table 1-3 were included in this study and dispatched at 100% of rated capacity.

The study included stability analysis of each proposed interconnection request. Contingencies that resulted in a prior-queued project tripping off-line, if any, were re-run with the prior-queued project's voltage and frequency tripping disabled. A power factor analysis was performed for the wind farms in Table 1-1.

ATC (Available Transfer Capability) studies were not performed as part of this study. These studies will be required at the time transmission service is actually requested. Additional transmission upgrades may be required based on that analysis.

Study assumptions in general have been based on Excel's knowledge of the electric power system and on the specific information and data provided by SPP. The accuracy of the conclusions contained within this study is sensitive to the assumptions made with respect to generation additions and transmission improvements being contemplated. Changes in the assumptions of the timing of other generation additions or transmission improvements will affect this study's conclusions.

Table 1-3. Nearby Interconnection Requests Already in the Queue

Request	Size	Generator Model	Point of Interconnection	POI Bus	Gen Buses
GEN-2002-004	199.5	GE.1.5MW	Latham 345kV	532800	547504 547505
GEN-2005-013	199.8	Vestas V90 1.8MW	Latham – Neosho 345kV	574000	574004
GEN-2007-025	300	Clipper 2.5MW	Wichita-Woodring 345kV	532781	1251 1252
GEN-2008-013	300	G.E. 1.5MW	Wichita – Woodring 345kV	210130	1131 1132 1133
GEN-2008-021	1250	Nuclear Steam Turbine	Wolf Creek 345kV	532794	532751
GEN-2008-127	200.1	Siemens 2.3MW	Tap Sooner – Rose Hill 345kV	573039	573033 573036
GEN-2009-025	59.4	Vestas V90 1.8MW	Tap Deerck – Sincblk2 69KV	573049	573053

2. Executive Summary

The GEN-2008-098 and GEN-2010-003 Impact Restudy evaluated the impacts of interconnecting the Table 1-1 study projects to the SPP transmission system.

Poorly damped oscillations of the study projects and the nearby Wolf Creek nuclear plant (GEN-2008-021) were found following four of the study faults. Fault "FLT_C3-6_3PH" (prior outage of Wolf Creek to Rose Hill 345 kV line with a fault on the GEN08-098 to LaCygne 345kV line, near LaCygne) shows the worst scenario with poorly damped oscillations.

In order to identify the impact of the study projects on this problem, the following cases were developed and tested for fault "FLT_C3-6_3PH":

- Pre-project Case with both GEN-2008-098 and GEN-2010-003 off-line
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 25%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 50%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 75%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 100% (the original study case)

Results show the study projects adversely impact the Wolf Creek generator damping at all study project output levels.

For the conditions with prior outage of one of the following two 345 kV lines, the study projects will be required to turn off in order to maintain a safe operating margin for the Wolf Creek nuclear plant.

- Wolf Creek to Rose Hill 345 kV line
- GEN08-098 to LaCygne 345kV line

Final power factor and capacitor requirements for the study projects are listed in Table 4-8.

With the assumptions and operation requirements described in this report, study projects GEN-2008-098 and GEN-2010-003 should be able to connect without causing any stability problems on the SPP transmission grid.

Any change in system or wind farm models or assumptions could change these results.

3. Study Development and Assumptions

3.1 Simulation Tools

The Siemens Power Technologies, Inc. PSS/E power system simulation program Version 30.3.3 was used in this study.

3.2 Models Used

SPP provided its latest stability database cases for each of the following categories:

- **<u>Category B1:</u>**
  Precondition:
  - All facilities in service
  - Wolf Creek generation operating at 1250 MW capacity
- **<u>Category C1:</u>**
  Precondition:
  - Wolf Creek – GEN-2008-098 line out of service
  - Wolf Creek generation reduced to 800MW
- **<u>Category C2:</u>**
  Precondition:
  - LaCygne – GEN-2008-098 line out of service
  - Wolf Creek generation reduced to 800MW
- **<u>Category C3:</u>**
  Precondition:
  - Wolf Creek – Rose Hill line out of service
  - Wolf Creek generation reduced to 800MW
- **<u>Category C4:</u>**
  Precondition:
  - Wolf Creek – Benton line out of service
  - Wolf Creek generation reduced to 800MW

All the database cases are based on the MDWG 2010 series, 2016 Light load season. The model included the study, concurrent, and prior-queued projects.

Power flow one-line diagrams of the study projects in Category B1 conditions are shown in Figure 3-1. As the figure shows, each wind farm model is represented by lumped equivalents including a generator, a step-up transformer, and a collector system impedance. The two study projects share the same substation transformer from 34.5kV to transmission voltage and a radial transmission line.

The plants for both GEN-2008-098 and GEN-2010-003 are assumed not to have the optional PPC control.

Steady-state and dynamic model data for the study plants are given in Appendix G.

A one-line diagram of the SPP 345 kV system in the study area is shown in Appendix H.

No special modeling is required of line relays in these cases, except for the special modeling related to the wind-turbine tripping.

3.3 Monitored Facilities

All generators and transmission buses in Areas 520, 523, 524, 525, 536, 538, 540, 541, and 544 were monitored.

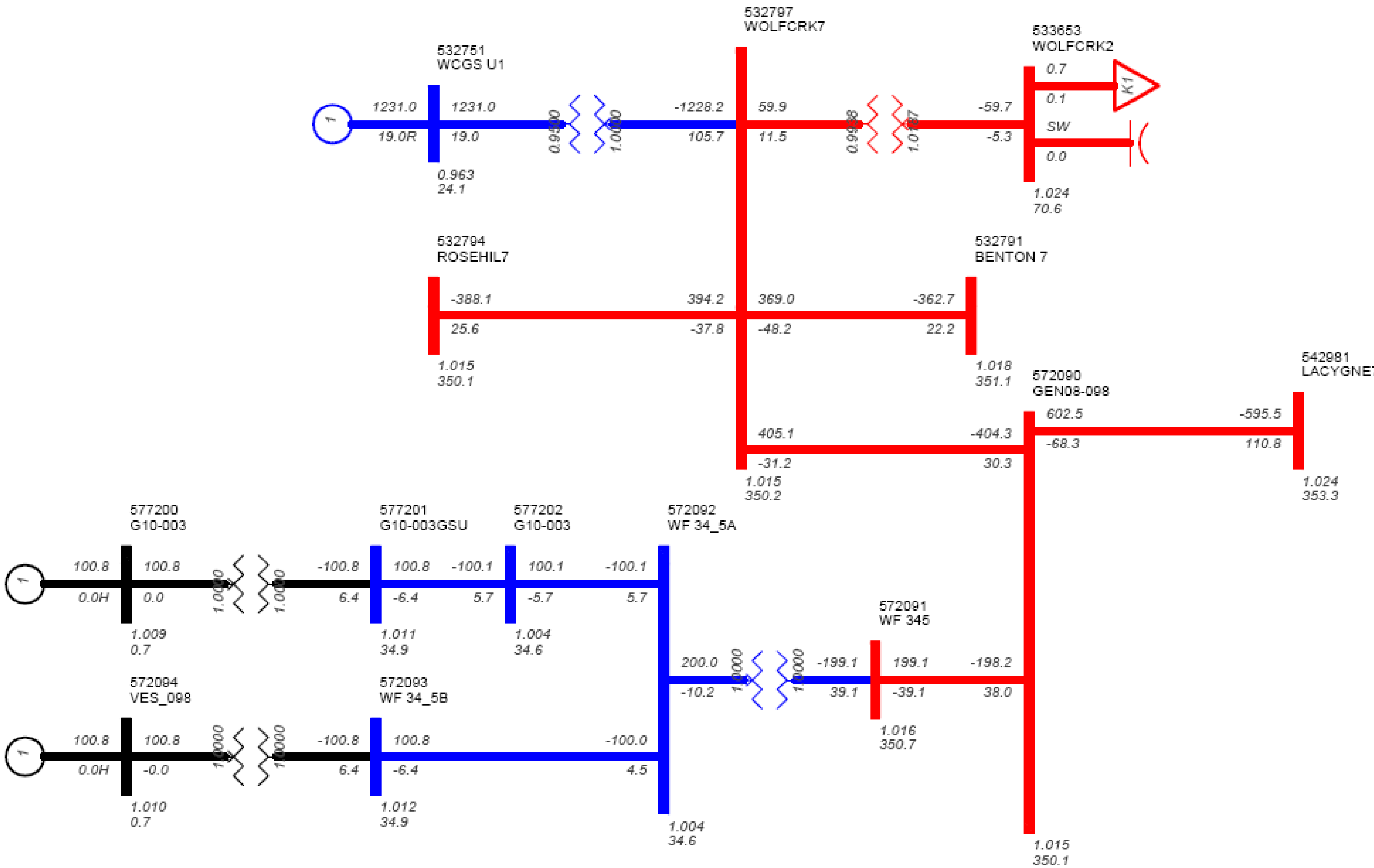

Figure 3-1. Power Flow One-line for GEN-2008-098, GEN-2010-003, and adjacent equipment (Category B1)

3.4 Performance Criteria

Any wind generators must comply with FERC Order 661A on low voltage ride through for wind farms. Therefore, the wind generators should not trip off line for faults for under voltage relay actuation. If a wind generator trips off line, an appropriately sized SVC or STATCOM device may need to be specified to keep the wind generator on-line for the fault. SPP was consulted to determine if the addition of an SVC or STATCOM is warranted for the specific condition.

Contingencies that resulted in a prior-queued project tripping off-line, if any, were re-run with the prior-queued project's voltage and frequency tripping disabled to check for stability issues.

Stability analysis was performed for each proposed interconnection request. Faults were simulated on transmission lines at the POI and on other nearby transmission equipment. Table 3-1 through Table 3-5 show the faults and network conditions that were simulated.

ATC studies were not performed as part of this study. These studies will be required at the time transmission service is actually requested. Additional transmission facilities may be required based on subsequent ATC analysis.

3.5 Performance Evaluation Methods

3.5.1 Modal Analysis

A modal analysis was performed for the Wolf Creek generator angle simulation results by using PSSPLT. The simulation results in the range of 7 to 20 seconds were chosen for the analysis to allow well-damped modes to die out. The remaining lightly damped modes are then characterized in terms of frequency and damping (i.e., their eigenvalues). This analysis also provides the mode shape (i.e., eigenvector) associated with each eigenvalue. For each contingency condition experiencing poorly damped oscillations, the most dominant complex eigenvalue with the highest eigenvector magnitude is reported. The calculation method of damping ratio and frequency of each eigenvalue is shown below:

For a complex eigenvalue: $a + bi$

Magnitude: $M = \sqrt{a^2 + b^2}$

Damping ratio: $d = (-1) * \frac{a}{M} * 100\%$

Frequency: $f = \frac{b}{2*\pi} \quad (Hz)$

If the damping ratio is positive, the oscillation is stable. The larger the damping ratio of the dominant eigenvalue, the faster the system settles to stable conditions. If the damping is negative, the oscillation is unstable.

3.5.2 Power Factor Analysis

A power factor analysis was performed for all study projects that are wind farms. The power factor analysis consisted of modeling a var generator in each wind farm holding a voltage schedule at the POI. The voltage schedule was set to the higher of the voltage with the wind farm off-line or 1.0 per unit.

If the required power factor at the POI is beyond the capability of the studied wind turbines, then capacitor banks would be considered. Factors used in sizing capacitor banks would include two requirements of FERC Order 661A: the ability of the wind farm to ride through low voltage with and without capacitor banks and the ability of the wind farm to recover to pre-fault voltage. If a wind generator trips on high voltage, a leading power factor may be required.

The Category B-1 saved case and the faults shown in Table 3-1 were used in the power factor analysis.

Table 3-1. Fault Definitions for Category B1

Preconditions:

- All facilities in service
- Wolf Creek generation operating at 1250 MW capacity

Cont. No.	Cont. Name	Description
1	FLT_B1-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
2	FLT_B1-2_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
3	FLT_B1-3_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
4	FLT_B1-4_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
5	FLT_B1-5_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
6	FLT_B1-6_3PH	3 phase fault on the LaCygne (542981) – GEN08-098 (572090) 345kV line near LaCygne. a. Apply fault at the LaCygne 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
7	FLT_B1-7_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton. a. Apply fault at the Benton 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
8	FLT_B1-8_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill. a. Apply fault at the Rose Hill 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.

Table 3-2. Fault Definitions for Category C1

Preconditions:

- Wolf Creek – GEN-2008-098 line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description
1	FLT_C1-1_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
2	FLT_C1-2_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
3	FLT_C1-3_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton. a. Apply fault at the Benton 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
4	FLT_C1-4_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill. a. Apply fault at the Rose Hill 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.

Table 3-3. Fault Definitions for Category C2

Preconditions:

- LaCygne – GEN-2008-098 line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description
1	FLT_C2-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
2	FLT_C2-2_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
3	FLT_C2-3_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
4	FLT_C2-4_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
5	FLT_C2-5_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton. a. Apply fault at the Benton 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
6	FLT_C2-6_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill. a. Apply fault at the Rose Hill 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.

Table 3-4. Fault Definitions for Category C3

Preconditions:

- Wolf Creek – Rose Hill line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description
1	FLT_C3-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
2	FLT_C3-2_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
3	FLT_C3-3_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
4	FLT_C3-4_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton. a. Apply fault at the Benton 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
5	FLT_C3-5_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
6	FLT_C3-6_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near LaCygne. a. Apply fault at the LaCygne 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.

Table 3-5. Fault Definitions for Category C4

Preconditions:

- Wolf Creek – Benton line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description
1	FLT_C4-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
2	FLT_C4-2_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek. a. Apply fault at the Wolf Creek 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
3	FLT_C4-3_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
4	FLT_C4-4_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill. a. Apply fault at the Rose Hill 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
5	FLT_C4-5_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near GEN08-098. a. Apply fault at the GEN08-098 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.
6	FLT_C4-6_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near LaCygne. a. Apply fault at the LaCygne 345kV bus. b. Clear fault after 3.6 cycles by tripping the faulted line and remove the fault.

4. Results and Observations

4.1 Stability Analysis Results

Table 4-1 to Table 4-5 summarize the results. Figure 4-1 to Figure 4-3 show representative Category B1 plots for a fault at the POI of the study projects. Complete sets of plots for each category, each fault, and each project are included in Appendices A, B, C, D, and E.

Poorly damped oscillations of the study projects and the nearby Wolf Creek nuclear plant (GEN-2008-021) were found with the following faults:

- FLT_C2-3_3PH
- FLT_C2-6_3PH
- FLT_C3-5_3PH
- FLT_C3-6_3PH

Modal analysis described in Section 3.5.1 was performed for these faults. Results are shown in Table 4-6. Fault "FLT_C3-6_3PH" (prior outage of Wolf Creek to Rose Hill 345 kV line with a fault on the GEN08-098 to LaCygne 345kV line, near LaCygne) has the worst damping.

In order to identify the impact of the study projects on this problem, the following cases were developed and tested for fault "FLT_C3-6_3PH":

- Pre-project Case with both GEN-2008-098 and GEN-2010-003 off-line
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 25%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 50%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 75%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 100% (the original study case)

Figure 4-4 to Figure 4-7 show the generator angle of the Wolf Creek nuclear plant (GEN-2008-021) with different output levels comparing with Pre-project conditions following fault "FLT_C3-6_3PH".

Modal analysis was also performed for these five scenarios. Results are listed in Table 4-7.

Results show the study projects adversely impact the Wolf Creek generator damping.

For the conditions with prior outage of one of the following two 345 kV lines, the study projects will be required to turn off in order to maintain a safe operating margin for the Wolf Creek nuclear plant.

- Wolf Creek to Rose Hill 345 kV line
- GEN08-098 to LaCygne 345kV line

Table 4-1. Summary of Stability Results – Category B1

Preconditions:
- All facilities in service
- Wolf Creek generation operating at 1250 MW capacity

Cont. No.	Cont. Name	Description	Simulation Results
1	FLT_B1-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek.	OK
2	FLT_B1-2_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek.	OK
3	FLT_B1-3_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek.	OK
4	FLT_B1-4_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098.	OK
5	FLT_B1-5_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near GEN08-098.	OK
6	FLT_B1-6_3PH	3 phase fault on the LaCygne (542981) – GEN08-098 (572090) 345kV line near LaCygne.	OK
7	FLT_B1-7_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton.	OK
8	FLT_B1-8_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill.	OK

Table 4-2. Summary of Stability Results – Category C1

Preconditions:
- Wolf Creek – GEN-2008-098 line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description	Simulation Results
1	FLT_C1-1_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek.	OK
2	FLT_C1-2_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek.	OK
3	FLT_C1-3_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton.	OK
4	FLT_C1-4_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill.	OK

Table 4-3. Summary of Stability Results – Category C2

Preconditions:

- LaCygne – GEN-2008-098 line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description	Simulation Results
1	FLT_C2-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek.	GEN-2008-098 & GEN-2010-003 is isolated and tripped
2	FLT_C2-2_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek.	OK
3	FLT_C2-3_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek.	Poorly Damped Oscillation
4	FLT_C2-4_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098.	GEN-2008-098 & GEN-2010-003 is isolated and tripped
5	FLT_C2-5_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton.	OK
6	FLT_C2-6_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill.	Poorly Damped Oscillation

Table 4-4. Summary of Stability Results – Category C3

Preconditions:

- Wolf Creek – Rose Hill line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description	Simulation Results
1	FLT_C3-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek.	OK
2	FLT_C3-2_3PH	3 phase fault on the Wolf Creek (532797) – Benton (532791) 345kV line near Wolf Creek.	OK
3	FLT_C3-3_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098.	OK
4	FLT_C3-4_3PH	3 phase fault on the Benton (532791) – Wolf Creek (532797) 345kV line near Benton.	OK
5	FLT_C3-5_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near GEN08-098	Poorly Damped Oscillation
6	FLT_C3-6_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near LaCygne	Poorly Damped Oscillation

Table 4-5. Summary of Stability Results – Category C4

Preconditions:

- Wolf Creek – Benton line out of service
- Wolf Creek generation reduced to 800MW

Cont. No.	Cont. Name	Description	Simulation Results
1	FLT_C4-1_3PH	3 phase fault on the Wolf Creek (532797) – GEN08-098 (572090) 345kV line near Wolf Creek.	OK
2	FLT_C4-2_3PH	3 phase fault on the Wolf Creek (532797) – Rose Hill (532794) 345kV line near Wolf Creek.	OK
3	FLT_C4-3_3PH	3 phase fault on the GEN08-098 (572090) – Wolf Creek (532797) 345kV line near GEN08-098.	OK
4	FLT_C4-4_3PH	3 phase fault on the Rose Hill (532794) – Wolf Creek (532797) 345kV line near Rose Hill.	OK
5	FLT_C4-5_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near GEN08-098.	OK
6	FLT_C4-6_3PH	3 phase fault on the GEN08-098 (572090) – LaCygne (542981) 345kV line near LaCygne.	OK

Table 4-6. Modal Analysis Results for the Wolf Creek Generator Angle following Contingencies with Poorly Damped Oscillations

Faults	EIGENVALUE				
	REAL	IMAGINARY	MAGNITUDE	DAMPING	FREQUENCY
C2-3	-2.88E-02	4.533	4.534	0.63%	0.722
C2-6	-2.92E-02	4.536	4.536	0.64%	0.722
C3-5	-2.30E-02	4.502	4.502	0.51%	0.717
C3-6	-2.19E-02	4.503	4.503	0.49%	0.717

Table 4-7. Modal Analysis Results for the Wolf Creek Generator Angle following fault "FLT_C3-6_3PH"

Faults	EIGENVALUE				
	REAL	IMAGINARY	MAGNITUDE	DAMPING	FREQUENCY
Output-0%	-1.20E-01	4.804	4.806	2.49%	0.765
Output-25%	-9.08E-02	4.737	4.738	1.92%	0.754
Output-50%	-6.72E-02	4.665	4.666	1.44%	0.743
Output-75%	-4.34E-02	4.589	4.589	0.94%	0.731
Output-100%	-2.19E-02	4.503	4.503	0.49%	0.717

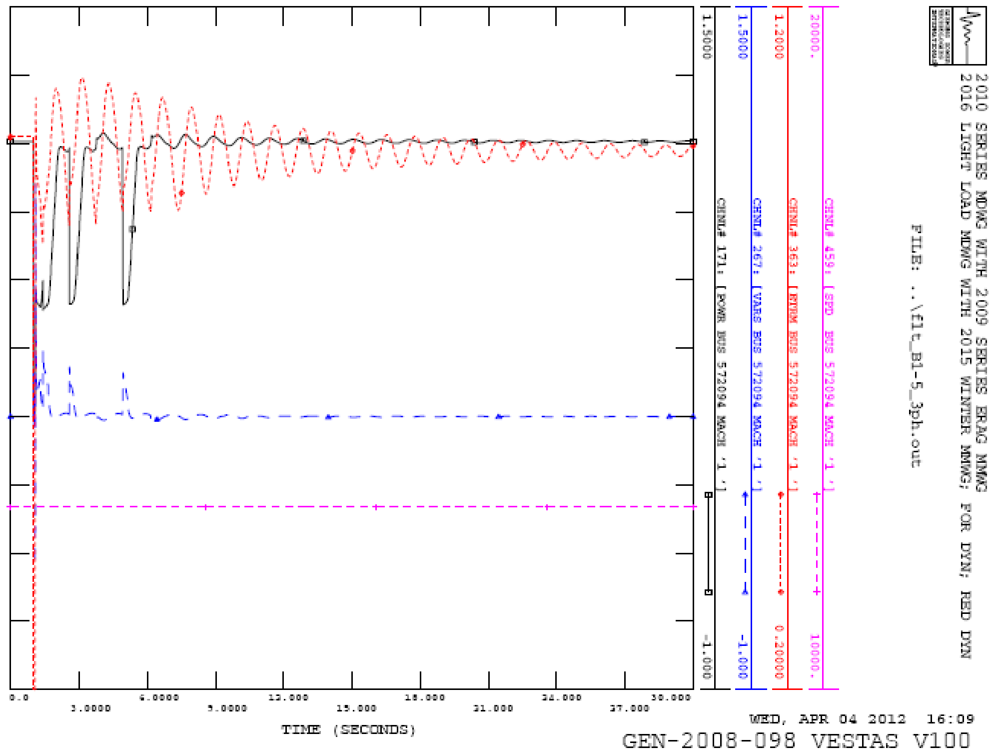

Figure 4-1. GEN-2008-098 Plot for Category B1 Fault 5 – 3-Phase fault on the GEN08-098 (572090) to LaCygne (542981) 345kV line, near GEN08-098

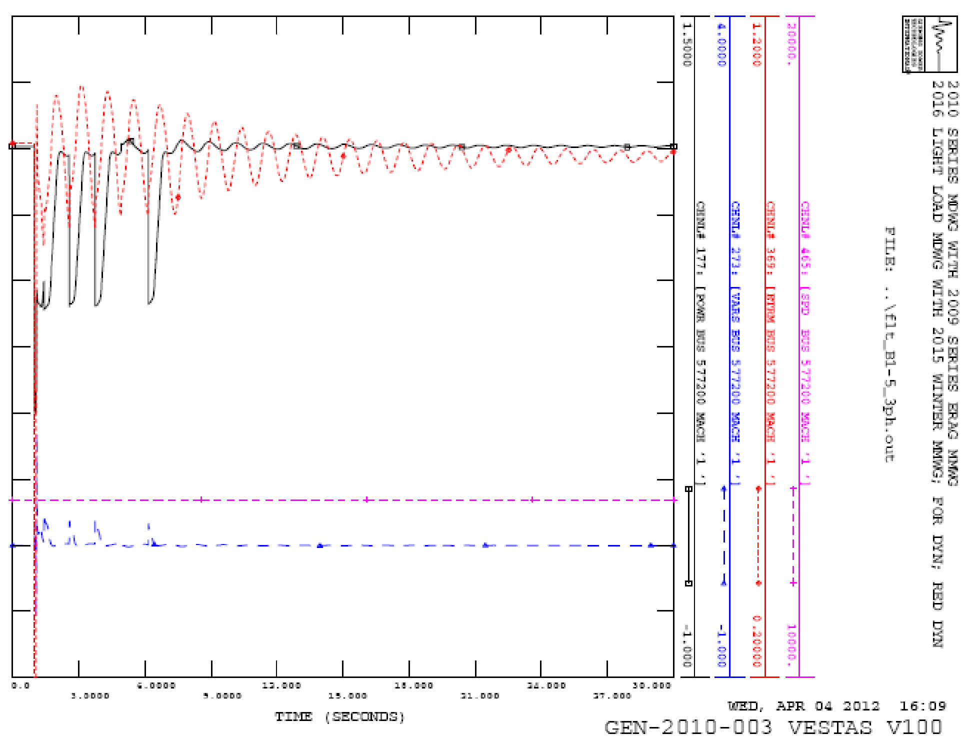

Figure 4-2. GEN-2010-003 Plot for Category B1 Fault 5 – 3-Phase fault on the GEN08-098 (572090) to LaCygne (542981) 345kV line, near GEN08-098

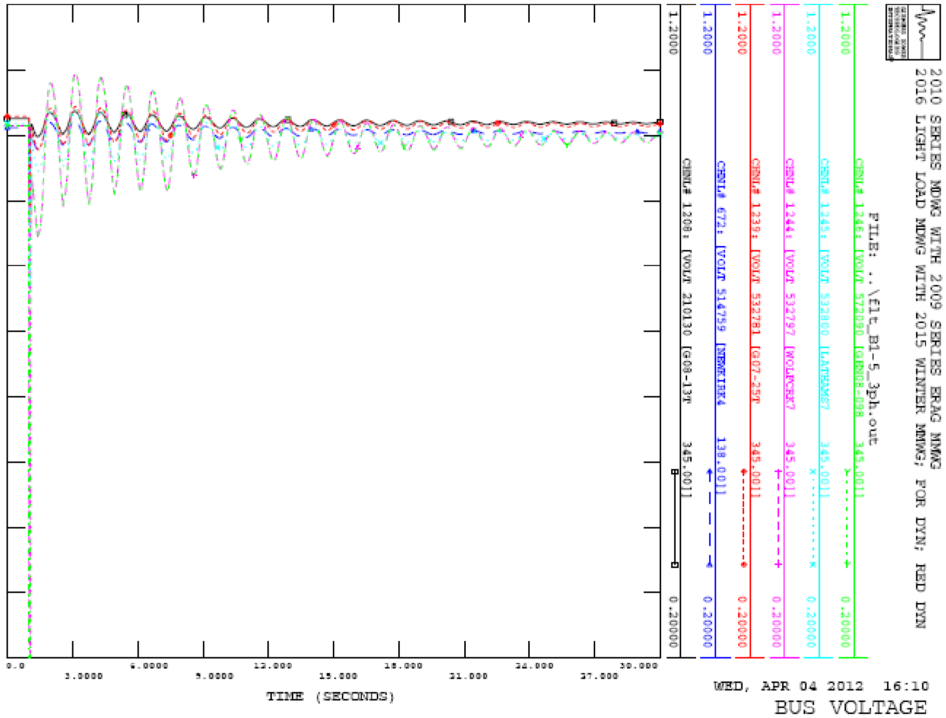

Figure 4-3. POI Voltages for Category B1 Fault 5 – 3-Phase fault on the GEN08-098 (572090) to LaCygne (542981) 345kV line, near GEN08-098

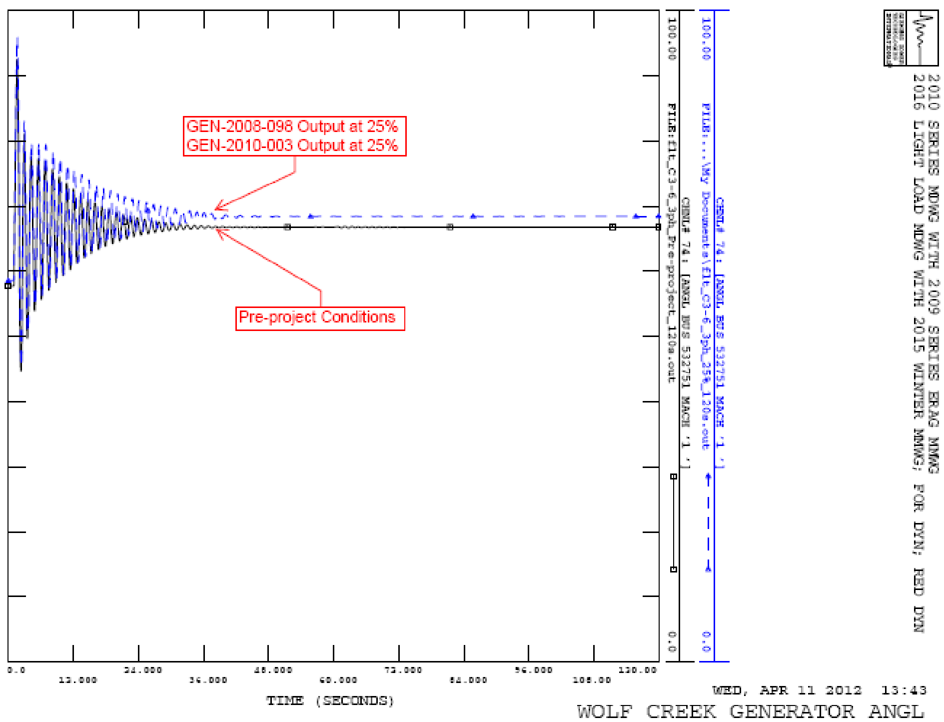

Figure 4-4. Generator Angle of the Wolf Creek Nuclear Plant (GEN-2008-021) for Category C3 Fault 6 – 3-Phase Fault on the GEN08-098 (572090) – LaCygne (542981) 345kV Line, near LaCygne – (With the Study Projects Outputs at 25% comparing with Pre-project Condition)

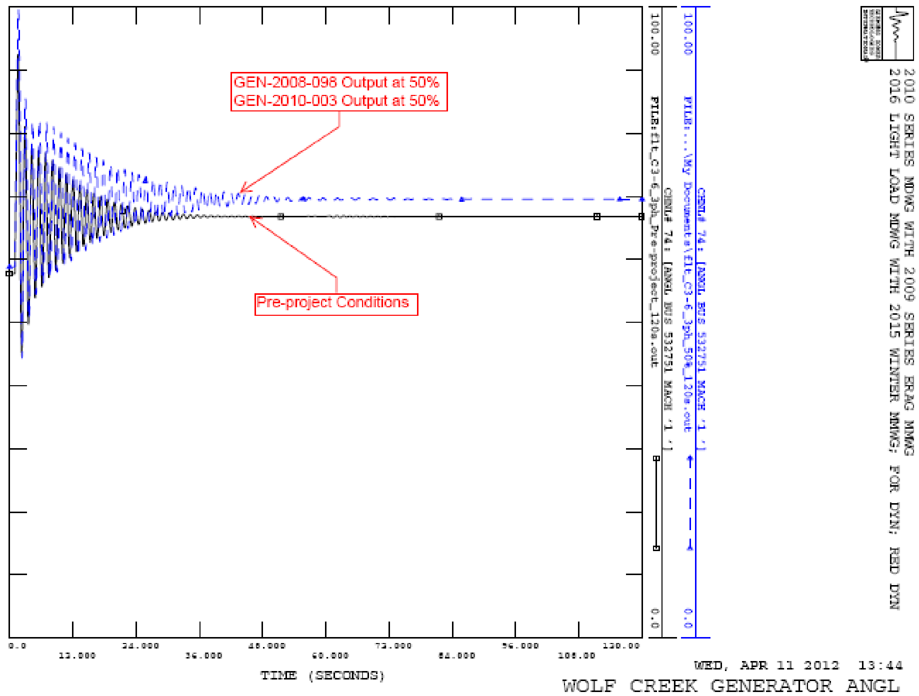

Figure 4-5. Generator Angle of the Wolf Creek Nuclear Plant (GEN-2008-021) for Category C3 Fault 6 – 3-Phase Fault on the GEN08-098 (572090) – LaCygne (542981) 345kV Line, near LaCygne – (With the Study Projects Outputs at 50% comparing with Pre-project Condition)

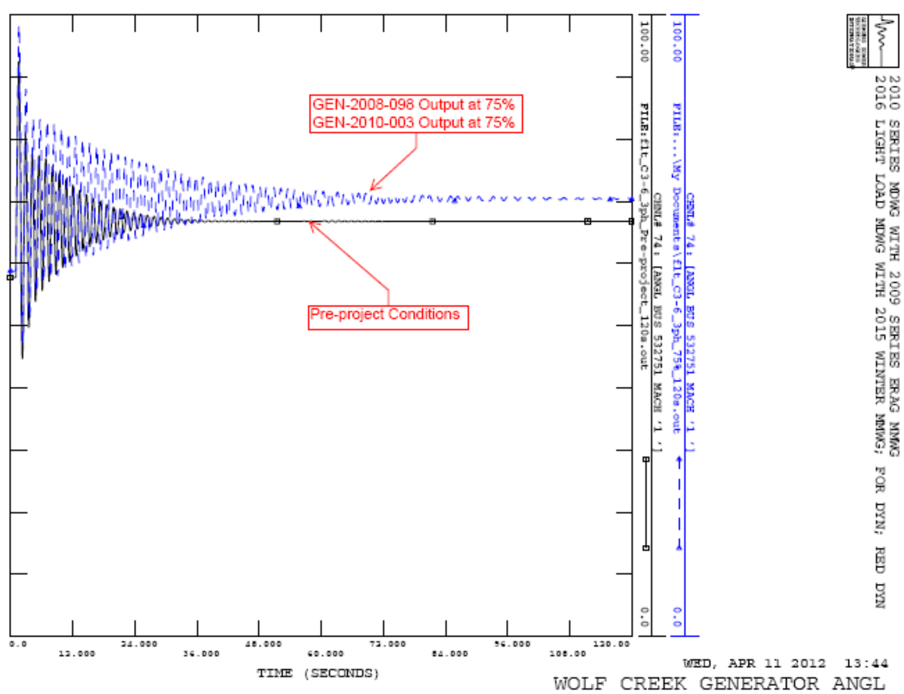

Figure 4-6. Generator Angle of the Wolf Creek Nuclear Plant (GEN-2008-021) for Category C3 Fault 6 – 3-Phase Fault on the GEN08-098 (572090) – LaCygne (542981) 345kV Line, near LaCygne – (With the Study Projects Outputs at 75% comparing with Pre-project Condition)

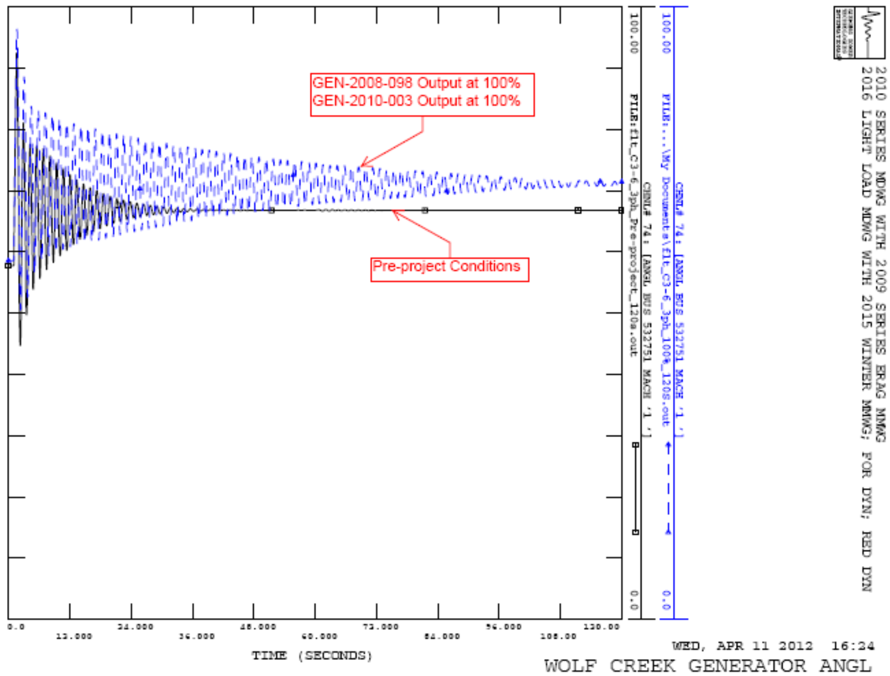

Figure 4-7. Generator Angle of the Wolf Creek Nuclear Plant (GEN-2008-021) for Category C3 Fault 6 – 3-Phase Fault on the GEN08-098 (572090) – LaCygne (542981) 345kV Line, near LaCygne – (With the Study Projects Outputs at 100% comparing with Pre-project Condition)

4.2 Power Factor Requirements

All stability faults were tested as power flow contingencies to determine the power factor requirements for the wind farm study projects to maintain scheduled voltage at their respective points of interconnection (POI). The voltage schedules are set equal to the voltages at the POIs before the projects are added, with a minimum of 1.0 per unit. Fictitious reactive power sources were added to the study projects to maintain scheduled voltage during all studied contingencies. The MW and Mvar injections from the study projects at the POIs were recorded and the resulting power factors were calculated for all contingencies for each category. The most leading and most lagging power factors determine the minimum power factor range capability that the study projects must install before commercial operation.

If more than one study project shared a single POI, the projects were grouped together and a common power factor requirement was determined for those study projects. This ensures that none of the study projects is required to provide more or less than its fair share of the reactive power requirements at a single POI. *Prior-queued* projects at the same POI, if any, were not grouped with the study projects because their interconnection requirements were determined in previous studies. The voltage schedules of prior-queued and study projects at the same POI were coordinated.

Per FERC and SPP Tariff requirements, if the power factor needed to maintain scheduled voltage is less than 0.95 lagging, then the requirement is limited to 0.95 lagging. The lower limit for leading power factor requirement is also 0.95. If a project never operated leading under any contingency, then the leading requirement is set to 1.0. The same applies on the lagging side. Estimates were made of the capacitor additions needed to meet the lagging power factor requirement.

The final power factor requirements are shown in Table 4-8 below. These are only the minimum power factor ranges based on steady-state analysis. A project developer may install more capability than this if desired.

The full details for each contingency with each category case are given in Appendix F.

Table 4-8. Power Factor Requirements [1]

Request	Size (MW)	Generator Model	Point of Interconnection	Power Factor Analysis Requirement[4]	
				Lagging [2]	Leading [3]
GEN-2008-098	100.8	Vestas V100 1.8MW	Wolf Creek – LaCygne 345kV	0.974	0.950
GEN-2010-003	100.8	Vestas V100 1.8MW	Gen-2008-098 addition		

Notes:
1. For each plant, the table shows the minimum required power factor capability at the point of interconnection that must be designed and installed with the plant. The power factor capability at the POI includes the net effect of the generators, transformers, line impedances, and any reactive compensation devices installed on the plant side of the meter. Installing more capability than the minimum requirement is acceptable.
2. Lagging is when the generating plant is supplying reactive power to the transmission grid. In this situation, the alternating current sinusoid “lags” behind the alternating voltage sinusoid, meaning that the current peaks shortly after the voltage.
3. Leading is when the generating plant is taking reactive power from the transmission grid. In this situation, the alternating current sinusoid “leads” the alternating voltage sinusoid, meaning that the current peaks shortly before the voltage.
4. Since this analysis shows that reactive power is required by the wind farm facility, the final wind farm requirement for power factor will be the standard pro-forma 95% lagging (providing vars) and 95% leading (absorbing vars) at the point of interconnection.

5. Conclusions

The GEN-2008-098 and GEN-2010-003 Impact Restudy evaluated the impacts of interconnecting the projects shown below.

Table 5-1. Interconnection Requests Evaluated in this Study

Request	Size (MW)	Wind Turbine Model	Point of Interconnection	POI Bus	Gen Buses
GEN-2008-098	100.8	Vestas V100 VCSS 1.8MW	Wolf Creek – LaCygne 345kV	572090	572094
GEN-2010-003	100.8	Vestas V100 VCSS 1.8MW	Gen-2008-098 addition	572090	577200

Poorly damped oscillations of the study projects and the nearby Wolf Creek nuclear plant (GEN-2008-021) were found following some of the study faults. Fault “FLT_C3-6_3PH” (prior outage of Wolf Creek to Rose Hill 345 kV line with a fault on the GEN08-098 to LaCygne 345kV line, near LaCygne) shows the worst scenario with poorly damped oscillations.

In order to identify the impact of the study projects on this problem, the following cases were developed and tested for fault “FLT_C3-6_3PH”:

- Pre-project Case with both GEN-2008-098 and GEN-2010-003 turning off-line
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 25%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 50%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 75%
- Case with both GEN-2008-098 and GEN-2010-003 outputs at 100% (the original study case)

Results show the study projects adversely impact the Wolf Creek generator damping at all study project output levels.

For the conditions with prior outage of one of the following two 345 kV lines, the study projects will be required to turn off in order to maintain a safe operating margin for the Wolf Creek nuclear plant.

- Wolf Creek to Rose Hill 345 kV line
- GEN08-098 to LaCygne 345kV line

Final power factor and capacitor requirements for the study projects are listed in Table 4-8.

With the assumptions and operation requirements described in this report, study projects GEN-2008-098 and GEN-2010-003 should be able to connect without causing any stability problems on the SPP transmission grid.

Any change in system or wind farm models or assumptions could change these results.

Appendix A – Category B1 Plots

See attachments.

Appendix B – Category C1 Plots

See attachments.

Appendix C – Category C2 Plots

See attachments.

Appendix D – Category C3 Plots

See attachments.

Appendix E – Category C4 Plots

See attachments.

Appendix F – Power Factor Details

See attachment.

Appendix G – Project Model Data

See attachment.