Impact Study for Generation Interconnection Request GEN–2005–017

SPP Tariff Studies
(#GEN-2005-017)

January, 2007

Executive Summary

<OMITTED TEXT> (Customer) has requested an Impact Study for the purpose of interconnecting a 340MW wind farm within the control area of Southwestern Public Service Company (d/b/a Xcel Energy) (SPS). The plant site is located in Sherman County, Texas along the Potter-Finney 345kV transmission line. The proposed method of interconnection is to build a new 345kV switching station that interconnects into the Potter-Finney 345kV line. The proposed in-service date is December 31, 2007.

This study has determined the requirements to interconnect the 340MW of generation is a new 345kV ring bus substation located on the Potter-Finney 345kV line. The station will have terminals to the south (Potter), north (Finney or prior queued wind farms), and to the Customer facility. The Customer will be required to install 83Mvar of capacitors within their interconnection facilities. The Customer will be responsible for paying for the installation of a 345kV line reactor on the line to the north. Depending upon the status of the prior queued wind farms, the Customer could be required to pay for the installation of a 345kV line reactor and for a 115kV, 50Mvar static var compensator (SVC) at one of the prior queued project's switchyard.

A stability study was conducted by ABB Consulting and is included in Attachment 1. The stability study showed no issues regarding the generation request. A transient overvoltage analysis was conducted by Shawnee Power Consulting. The results of this study can be determined that at least one 345kV line reactor is necessary for the interconnection of the generation. The results from this study can be found in Table 1. The entire study is available upon request.

The total minimum cost for building the new 345kV ring bus substation required for stand alone interconnection is $5,250,000. This cost is dependent upon the status of the two prior queued interconnection projects on the Potter – Finney 345kV line. These could be as high as $10,250,000 (see Table 1). This cost does not include building the Customer's 345kV and 115kV facilities up to 345kV switching station, the point of the change of ownership. This cost does not include the results of a short circuit analysis, which will be conducted if the Customer enters into a Facility Study Agreement.

The required interconnection costs listed in Table 3 do not include all costs associated with the deliverability of the energy to final customers. These costs are determined by separate studies if the Customer requests transmission service through Southwest Power Pool's OASIS.

Introduction

<OMITTED TEXT> (Customer) has requested an Impact Study for the purpose of interconnecting a 340MW wind farm within the control area of Southwestern Public Service Company (d/b/a Xcel Energy) (SPS). The plant site is located in Sherman County, Texas near the Potter-Finney 345kV transmission line. The proposed method of interconnection is to build a new 345kV ring bus switching station that interconnects into the Potter-Finney 345kV line. The proposed in-service date is December 31, 2007.

Interconnection Facilities

The primary objective of this study is to identify the system problems associated with connecting the plant into the area transmission system. The Impact and other subsequent Interconnection Studies are designed to identify attachment facilities, Network Upgrades and other direct assignment facilities needed to accept power into the grid at the interconnection receipt point.

The requirements for interconnection of the 340MW wind farm consist of building a new 345kV ring bus with three terminals, one each to Potter County Interchange, Finney County Interchange (or a prior queued wind farm), and one to the Customer wind farm. This station will be constructed, owned, and maintained by SPS. The Customer's facility will consist of a 345kV line that will connect the 345kV switching station to a 345/115/34.5kV substation to built, owned, and maintained by the Customer. The Customer 345/115/34.5kV substation will have two 345/34.5kV substation transformers and a 345/115kV transformer. Each of the two 345/34.5kV transformers will collect the energy from approximately eighty-six (86) General Electric 1.5MW wind turbines for a total power output of 129MW for each transformer. The 345/115kV transformer will connect to a 115kV line that will interconnect into a second Customer substation with a 115/34.5kV transformer. The second Customer substation will collect the energy from fifty-three (53) General Electric 1.5MW wind turbines for a total output of 79.5MW. The wind farm will have a total output of 339MW.

Due to reactive power losses on the wind turbine collector system and reactive losses due to the 345kV line reactors that are required for the project, the Customer will be required to install 83Mvar of capacitors within their facilities. Each of the 345/34.5kV transformers will be required to have a staged 34.5kV, 30Mvar capacitor bank on the 34.5kV bus of each transformer. At the 115/34.5kV transformer station, the Customer will be required to install a 115kV, 23Mvar capacitor bank on the 115kV bus.

There are two previous queued requests that have requested interconnection along the Potter-Finney 345kV line. The requests are GEN-2002-008 and GEN-2003-013. GEN-2002-008 is north of the study project (toward Finney). GEN-2003-013 is north of GEN-2002-008. As of the writing of this study, both of these requests have executed Interconnection Agreements that have been placed in suspension by the Customer. The Facilities required by this request will depend upon the status of the two prior queued projects.

The 345kV switching station will also include a 345kV line reactor on the terminal looking toward GEN-2002-008 (Finney). The size of this line reactor is determined by whether the two prior queued projects come off of suspension. These costs can be seen in Table 1.

If both prior queued request come off of suspension and are eventually built, combined with this request there will be over 770MW of wind generation on the 345kV line section between Potter and Finney. There will also be over 200MVar of line reactors on this line section. Due to these considerations, a static var compensator device (SVC) will be required by the Customer to be installed at the switching station for GEN-2002-008 to prevent possible voltage collapse for an outage of the 345kV line from Finney – GEN-2003-013. This location for this SVC has been chosen due to its central location on the 345kV line between Potter and Finney. This SVC device will be constructed, owned, and maintained by SPS and will be paid for by the Customer of this request. This SVC device has been sized at 50Mvar and will be placed on the 115kV bus at the switching station for GEN-2002-008. The approximate cost of this device is $5,000,000. Please refer to Table 1.

This SVC device will only be required if the GEN-2002-008 and GEN-2003-013 generation interconnection request are both built in addition to the study project. If, at this time, additional transmission outlets have been constructed to deliver energy from the Potter-Finney 345kV line (i.e. a new 345kV line to the east or a new 345/115kV stepdown substation to the SPS 115kV system) then this device may not be required.

Table 1: Scenarios for GEN-2005-017

Scenario	Line Reactors/ Static Var Compensators to be Installed	Approx. Cost to Customer
GEN-2002-008 and GEN-2003-013 come off of suspension and are both built	• 25 MVAR Line Reactor to be installed at GEN-2005-017 • 115kV, 50Mvar Static Var Compensator to be installed at GEN-2002-008	$6,250,000
GEN-2002-008 comes off suspension; GEN-2003-013 does not	• 27 MVar Line Reactor to be installed at GEN-2005-017 • 50 MVar Line Reactor to be installed at GEN-2002-008	$3,000,000
GEN-2003-013 comes off suspension; GEN-2002-008 does not	• 30 Mvar Line Reactor to be installed at GEN-2005-017 • 27Mvar Line Reactor to be installed at GEN-2003-013	$3,000,000
GEN-2002-008 and GEN-2003-013 both do not come off suspension	• 75 Mvar Line Reactor to be installed at GEN-2005-017	$1,900,000

The total cost for building a new 345kV Switching Station (not including the Line Reactor and SVC costs above) is $4,000,000 as shown in Table 3. These costs do not include the line reactor/SVC costs in Table 1. These costs do include Customer facilities up to the point of interconnection. These costs do not include the costs associated with short circuit analysis. Short circuit analysis will be conducted if the Customer chooses to continue on with the request into a Facility Study.

A preliminary one-line drawing of the interconnection and direct assigned facilities are shown in Figure 1.

Table 2: Direct Assignment Facilities

Facility	ESTIMATED COST (2006 DOLLARS)
Customer – 345-115-34.5kV Substation facilities including two 34.5kV 30MVAR and one 115kV 23MVAR capacitor bank.	
Customer – 345kV line between Customer substation and new SPS switching station.	
Customer - Right-of-Way for Customer Substation & Line.	
Total	*

Note: *Estimates of cost to be determined by Customer.

Table 3: Required Interconnection Network Upgrade Facilities

Facility	ESTIMATED COST (2006 DOLLARS)
SPS - New 345kV switching station in existing Potter - Finney 345kV line.	$4,000,000
SPS – Static Var Compensator at GEN-2002-008	See Table 1
SPS – Line Reactors to be determined by Table 1	See Table 1
Total	**

** Cost to be determined by the Line Reactors / SVC to be installed

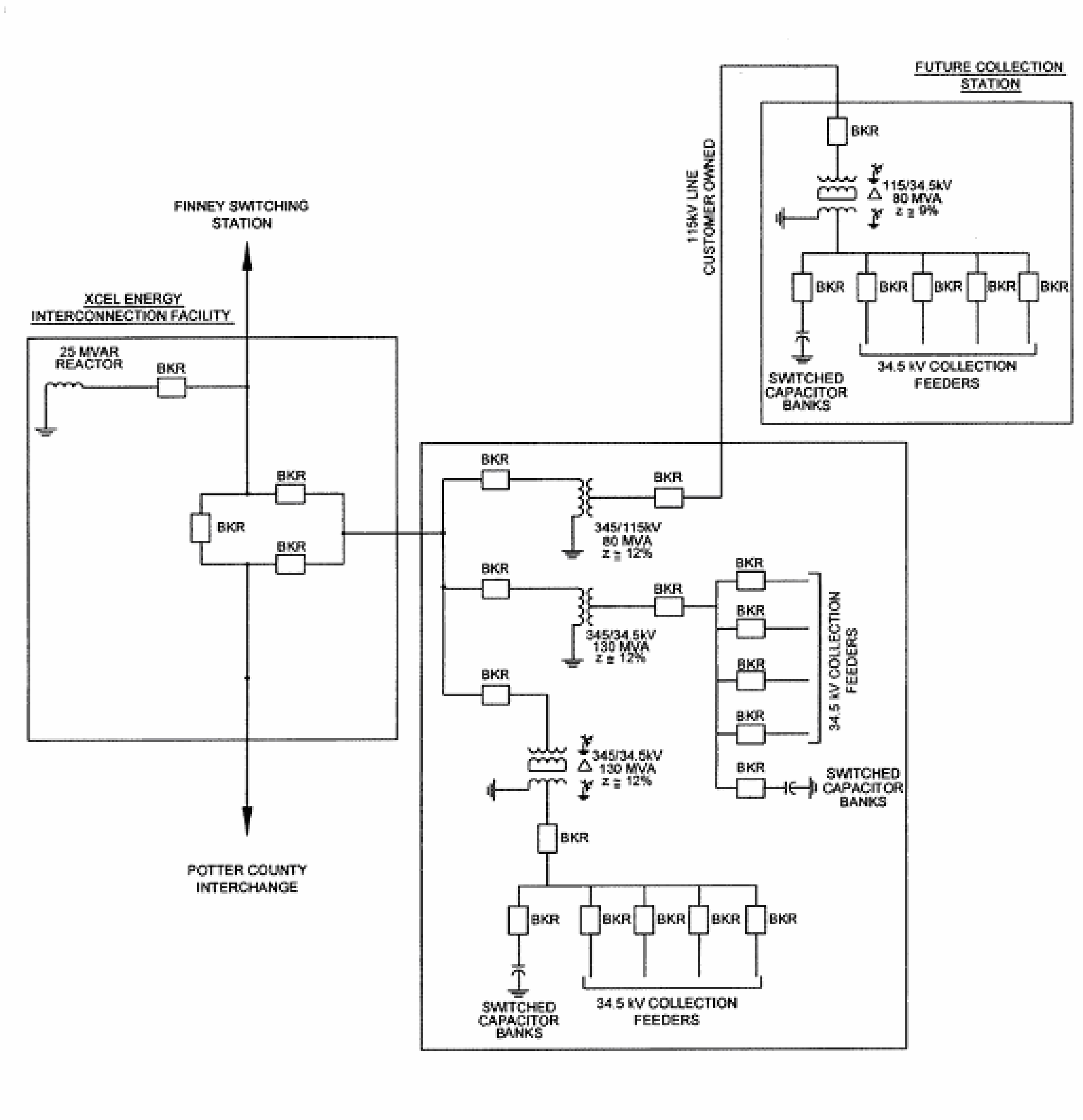

Figure 1: Proposed Interconnection
(Final substation design to be determined

Transient Overvoltage Analysis

A Transient Overvoltage Study was conducted for this request by Shawnee Power Consulting LLC in Williamsburg, VA. This study was conducted to determine the need and size of line reactors for the generation interconnection request. Several scenarios had to be studied due to the prior queued projects. The results of this study are shown in Table 1. The entire study is available upon request.

Dynamic Stability Analysis

A stability study was performed by ABB in Raleigh, NC for this generation request. That study is appended to this study as Attachment 1. The study showed that there were no issues related to angular stability for this generation request.

Reactive Compensation Requirements

The Feasibility Study for this request discussed voltage issues related to the addition of this generation. Due to the amount of requested generation (770MW) and proposed line reactance (200Mvar) on the line section between Potter and Finney, the Feasibility Study cited the need for a total of 120Mvar of reactive compensation for this wind farm including a 30MVar SVC at the Customer's substation. However, the Feasibility Study also noted that power flow solutions could not be obtained for certain outages along the Finney-Potter 345kV line section using this proposed configuration of reactive compensation.

The ABB study determined that 83Mvar of capacitors are required in the Customer facilities to compensate for collector system losses that are required regardless of the prior queued project's status.

The dynamic reactive compensation requirements were revisited with the assumption that both prior queued projects are in service and no transmission reinforcements have been constructed along the line corridor from Potter 345kV – Finney 345kV. The contingency that was studied was an outage of the line from Finney-GEN-2003-013.

For this outage, all of the proposed wind generation's only outlet to the rest of the transmission system is through the Potter County 345/230kV autotransformer. In order to avoid possible voltage collapse in this situation, it was determined the optimal location to install the proposed SVC device is at the GEN-2002-008 switching station 115kV bus. This location is preferred because this location is approximately in the middle of the Potter-Finney line section. The size of the SVC was determined to be 50Mvar.

As stated above, this SVC requirement is only required if both prior queued projects are in service and no transmission reinforcements have been constructed (such as a new 345kV line or a new 345/115kV stepdown station in the border area between Texas and Oklahoma). If these conditions are not present when the Customer is preparing to construct, the Customer may ask for this issue to be revisited.

In the event that the Customer decides to change the wind turbine type from G.E. to another manufacturer, the entire reactive compensation requirements will need to be re-evaulated.

Conclusion

The minimum cost of interconnecting the Customer's interconnection request is estimated at $5,250,000 (not including costs for line reactors and SVCs) for SPS's interconnection Network Upgrade facilities listed in Table 3. At this time, the cost estimates for other Direct Assignment facilities including those in Table 2 have not been defined by the Customer. As stated earlier, the local projects that were previously queued are assumed to be in service in this Impact Study.

The Customer will be required to install 83Mvar of capacitors within their interconnection facilities.

Based upon the status of the prior queued projects on the Potter-Finney 345kV line, the Customer will be responsible for paying for facilities that will be constructed in the prior queued project's switching station. See Table 1.

These interconnection costs do not include any cost that may be associated with short circuit analysis. A short circuit study will be conducted if the Customer signs a Facility Study Agreement.

The required interconnection costs listed in Table 2 do not include all costs associated with the deliverability of the energy to final customers. These costs are determined by separate studies if the Customer requests transmission service through Southwest Power Pool's OASIS.

ATTACHMENT 1.

STABILITY STUDY

POWER SYSTEMS DIVISION
GRID SYSTEMS CONSULTING

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2005-017

FINAL REPORT

REPORT NO.: 2006-11391-R0
Issued: January 8, 2007

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ABB Inc – Grid Systems Consulting

Technical Report

Southwest Power Pool	**No.** 2006-11391-R0	
Impact Study for Generation Interconnection request GEN-2005-017	1/8/2007	# Pages 14

Author(s):	**Reviewed by:**	**Approved by:**
Shu Liu	Bill Quaintance	Willie Wong

Executive Summary

Southwest Power Pool (SPP) has commissioned ABB Inc., to perform a Generation Interconnection Impact study of a new 340 MW wind farm in Sherman County, Texas. This wind farm will be interconnected to the existing Potter-Finney 345 kV transmission line 60 miles from Potter, which is owned by Xcel Energy (d/b/a SWPS). This plant will comprise 226 GE 1.5 MW wind turbine generators. The interconnection impact study includes only the stability analysis. The feasibility (power flow) study was not performed as a part of this study.

The objective of this study is to evaluate the impact on system stability after connecting the GEN-2005-017 to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2007 Winter Peak and the 2011 Summer Peak, provided by SPP.

The SPP system will be stable following all the simulated faults with the proposed GEN-2005-017 project in-service.

One group of generators of GEN-2005-017 will be tripped due to low voltage for a fault at the interconnection point. Undervoltage protection trip settings are the reason for this.

With an upgraded low voltage ride-through package (LVRT II), all generators of GEN-2005-017 will stay on-line for faults at the interconnection point and the SPP system will be stable.

GEN-2002-08 will trip due to low voltage for a fault on the Potter County to Bushland 230 kV line for both pre- and post-GEN-2005-017 cases. Undervoltage protection trip settings are the cause. This tripping is not caused by addition of GEN-2005-017.

A total of 83 Mvar of capacitors are required at the GEN-2005-017 34.5 kV buses for steady-state stability purposes.

Rev No.	Revision Description	Date	Authored by	Reviewed by	Approved by
0	Final Report	1/8/2007	Shu Liu	Bill Quaintance	Willie Wong
DISTRIBUTION: Charles Hendrix – Southwest Power Pool					

Based on the results of stability analysis it can be concluded that the proposed GEN-2005-017 project does not adversely impact the stability of the SPP system if the recommended upgrades (LVRT and capacitors) are included.

The results of this analysis are based on available data and assumptions made at the time of conducting this study. If any of the data and/or assumptions made in developing the study model change, the results provided in this report may not apply.

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1 INTRODUCTION

Southwest Power Pool (SPP) has commissioned ABB Inc., to perform a Generation Interconnection Impact study of a new 340 MW wind farm in Sherman County, Texas. This wind farm will be interconnected into the existing Potter-Finney 345 kV transmission line 60 miles from Potter, which is owned by Xcel Energy (d/b/a SWPS). This plant will comprise 226 GE 1.5 MW DFIG (doubly-fed induction generator) wind turbines. The interconnection study includes the stability analysis. The feasibility (power flow) study was not performed as a part of this study.

The objective of the impact study is to evaluate the impact on system stability after connecting the GEN-2005-017 to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2007 Winter Peak and the 2011 Summer Peak. Figure 1-1 shows the Point of interconnection for the GEN-2005-017. Figure 1-2 shows the schematic diagram for the interconnection of GEN-2005-017.

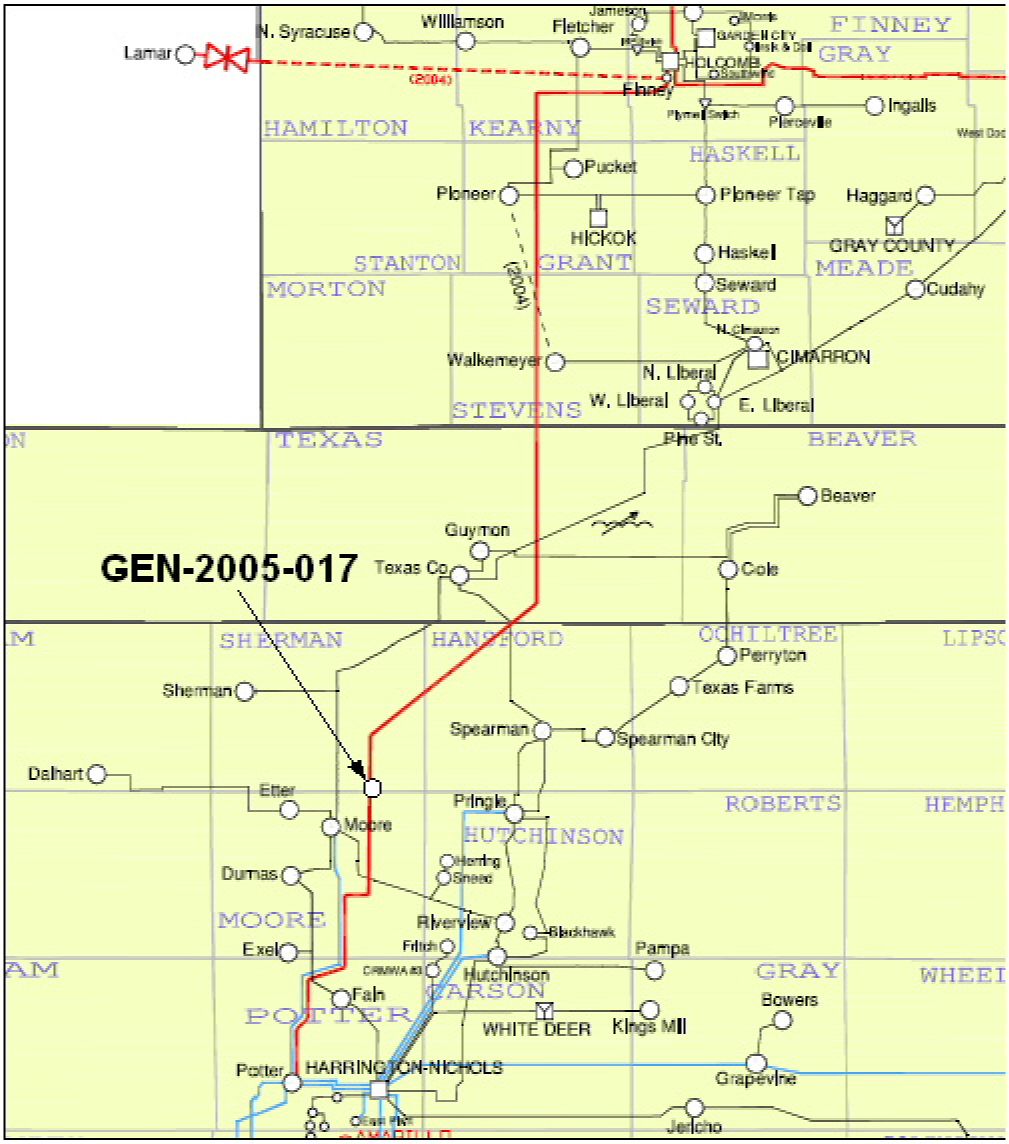

Figure 1-1: GEN-2005-017 Point of Interconnection

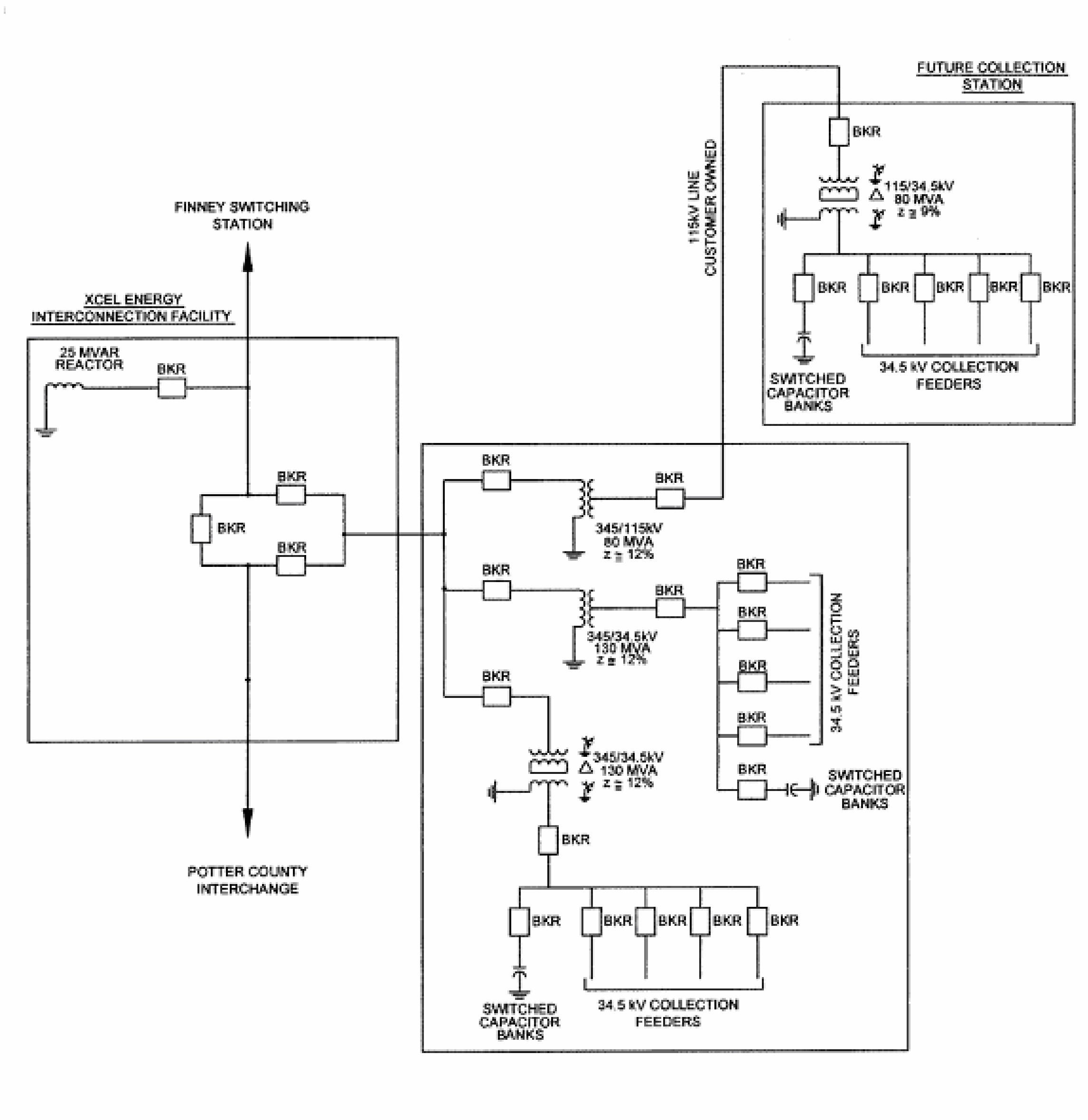

Figure 1-2: Schematic diagram for the interconnection of GEN-2005-017

2 STABILITY ANALYSIS

In this study, ABB investigated the stability of the system for faults in the vicinity of the proposed plant as defined by SPP. The faults involve three-phase and single-phase faults cleared by primary protection, re-closing with the fault still on, and then permanently clearing the fault with primary protection. Note that the 345 kV line sections between Potter and Finney include single-pole opening and reclosing before final three-phase opening for permanent faults.

2.1 STABILITY ANALYSIS METHODOLOGY

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 differences of the angular positions of synchronous machine rotors become constant following an aperiodic system disturbance."

Stability analysis was performed using Siemens-PTI's PSS/E dynamics program V29. Disturbances such as three-phase and single-phase line faults were simulated for the specified durations, including re-closing, and the synchronous machine rotor angles were monitored to make sure they maintained synchronism following the fault removal.

Single-phase line faults were simulated with the standard method of applying fault impedance to the positive sequence network to represent the effect of the negative and zero sequence networks on the positive sequence network. The fault impedance was computed to give a positive sequence voltage at the fault location of approximately 60% of pre-fault voltage, which is a typical value.

2.2 STUDY MODEL DEVELOPMENT

The study model consists of power flow cases and dynamics databases, developed as follows.

<u>Power Flow Case</u>

SPP provided two (2) Pre-project PSS/E power flow cases called "*gen05-17_11sp_base.sav*" representing the Summer Peak conditions of the SPP system for the year 2011 and the "*gen05-17_07wp_base.sav*" representing the Winter Peak conditions of the SPP system for the year 2007.

The proposed GEN-2005-017 project is comprised of 226 GE 1.5 MW wind turbine generators. The units will be connected to the Potter-Finney 345 kV transmission line by two two-winding 345/34.5 kV transformers and one two-winding 345/115 kV transformer. The proposed project was added to the Pre-project cases and the generation was dispatched by scaling down generation in AEPW (area 520, 340 MW). See Table 2-1 for details. Two power flow cases with GEN-2005-017 were established:

SP11-GEN-2005-017.SAV
WP07-GEN-2005-017.SAV

Figure 2-1 and Figure 2-2 show the power flow diagrams for the local area of Potter-Finney 345 kV transmission line with GEN-2005-017 in-service (Summer Peak 2011 and Winter Peak 2007 system conditions, respectively).

Table 2-1: GEN-2005-017 project details

System condition	MW	Location	Point of Interconnection	Sink
Summer Peak	340	Sherman County, Texas	Potter-Finney 345 kV transmission line	AEPW
Winter Peak	340	Sherman County, Texas	Potter-Finney 345 kV transmission line	AEPW

Wind Farm Power Flow Model

The GEN-2005-017 wind farm has 226 GE 1.5 MW wind turbine-generators. Two groups of wind turbine-generators which include 88 and 85 turbines respectively are modeled as two single machines. Each equivalent generator is added to the full SPP system model through a single equivalent GSU transformer, a single equivalent collector branch, and the 345/34.5 kV transformer. The rest of 53 wind turbine-generators are modeled as another single machine. This single equivalent generator and a single equivalent GSU transformer are connected to the 115/34.5 kV transformer through a single equivalent collector branch. This 115/34.5 kV transformer is connected to the full SPP system model through a 2.5-mile 115 kV transmission line and a 345/115 kV transformer. The detailed process of wind farm model development is included in Appendix A.

Stability Database

SPP provided the stability database in the form of a PSS/E dynamic dyr data file "*gen05-17_11sp_base.dyr*" to model the Summer Peak stability dynamics database for 2011 and "*gen05-17_07wp_base.dyr*" to model the Winter Peak stability dynamics database for the year 2007. Along with the above-mentioned files, idev and batch files were also provided to compile and link user-written models. The provided files required the use of PSS/E version 29.

The stability data for GEN-2005-017 was appended to the Pre-GEN-2005-017 snapshot. The stability model parameters were based on default data provided with the PTI GE Wind model. This model incorporates the standard ride-through capability that allows wind turbine generator operation below 70% terminal voltage for up to 100ms and instantaneous tripping (20ms) for terminal voltages below 30%. The wind farm was modeled assuming generator terminal voltage control.

The Power flow and stability model representations for GEN-2005-017 are included in Appendix B.

Table 2-2 lists the disturbances simulated for stability analysis. All transmission lines were assumed to have re-closing enabled. All faults were simulated for 10 seconds.

Table 2-2: List of Faults for Stability Analysis

FAULT	FAULT DESCRIPTION
FLT_1_3PH	a. Apply 3-phase fault at the Finney bus (50858). b. Clear fault after 3.5 cycles by removing the line from 90001 to 50858. c. Trip line from Finney-Lamar (50858-59998)
FLT_2_1PH	a. Apply 1-phase fault at the Finney bus (50858). b. Clear fault after 3.5 cycles by tripping one phase on the line from 90001 to 50858. c. Wait 20 cycles, and then re-close the phase in (b) into the fault. d. Leave fault on for 3.5 cycles, then trip the line in (b), and remove fault. e. Trip line from Finney-Lamar (50858-59998)
FLT_3_3PH	a. Apply 3-phase fault at the GEN-2002-008 bus (66661). b. Clear fault after 3.5 cycles by removing the line from 51700 to 66661. Remove the line reactor from service at GEN-2005-017.
FLT_4_1PH	a. Apply 1-phase fault at the GEN-2002-008 bus (66661). b. Clear fault after 3.5 cycles by tripping one phase on the line from 66661 to 51700. Remove line reactor from service at GEN-2005-017 c. Wait 20 cycles, and then re-close the phase in (b) into the fault and place reactor back in service. d. Leave fault on for 3.5 cycles, then trip the line in (b) remove the reactor at GEN-2005-017 and remove fault.
FLT_5_3PH	a. Apply 3-phase fault at the midpoint of the line (99996). b. Clear fault after 3.5 cycles by tripping the line from #66661 to #90001. Remove from service the reactors at each of the buses.
FLT_6_1PH	a. Apply 1-phase fault at the midpoint of the line (99996). b. Clear fault after 3.5 cycles by tripping one phase on the line from 66661 to 90001. c. Wait 20 cycles, and then re-close the phase in (b) into the fault. d. Leave fault on for 3.5 cycles, then trip the line in (b) trip the reactors and remove fault.
FLT_7_3PH	a. Apply 3-phase fault at the GEN-2005-017 bus (51700). b. Clear fault after 3.5 cycles by removing the line from 51700-50888 (the reactor at Potter will be automatically tripped).
FLT_8_1PH	a. Apply 1-phase fault at the GEN-2005-017 345kV bus (51700). b. Clear fault after 3 cycles by tripping one phase on the line from 51700 - 50888. c. Wait 20 cycles, and then re-close the phase in (b) into the fault. d. Leave fault on for 3 cycles, then trip the line in (b), (the reactor at Potter will be automatically tripped)
FLT_9_3PH	a. Apply 3-phase fault at the Holcomb bus (56449). b. Clear fault after 3 cycles by removing the line from 56449-50858.

FAULT	FAULT DESCRIPTION
FLT_10_1PH_A	a. Apply 1-phase fault at the Holcomb bus (56449). b. Clear fault after 3 cycles by tripping one phase on the line from 56449-50858. c. Wait 20 cycles, and then re-close the phase in (b) into the fault. d. Leave fault on for 3 cycles, then trip the line in (b).
FLT_10_1PH_B	a. Apply 1-phase fault at the Holcomb bus (56449). b. Clear fault after 3 cycles by tripping the line from 56449-50858. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 3 cycles, then trip the line in (b).
FLT_11_3PH	e. Apply 3-phase fault at the Grapevine bus (50827). f. Clear Fault after 5 cycles by removing line from 50827 – 54153. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_12_1PH	a. Apply 1-phase fault at the Grapevine bus (50827). b. Clear Fault after 5 cycles by removing line from 50827 – 54153. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_13_3PH	a. Apply 3-phase fault at the Plant X bus (51419). b. Clear Fault after 5 cycles by removing line from 50887 – 51419. g. Wait 20 cycles, and then re-close line in (b) into the fault. h. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_14_1PH	a. Apply 1-phase fault at the Plant X bus (51419). b. Clear Fault after 5 cycles by removing line from 50887 – 51419. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_15_3PH	a. Apply 3-phase fault at the Blackhawk bus (50718). b. Clear Fault after 5 cycles by removing line from 50652 – 50718. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_16_1PH	a. Apply 1-phase fault at the Blackhawk bus (50718). b. Clear Fault after 5 cycles by removing line from 50652 – 50718. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_17_3PH	a. Apply 3-phase fault at the Potter 230kV bus (50887). b. Clear Fault after 5 cycles by removing line from 50887 – 50993. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT_18_1PH	a. Apply 1-phase fault at the Potter 230kV bus (50887). b. Clear Fault after 5 cycles by removing line from 50887 – 50993. c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

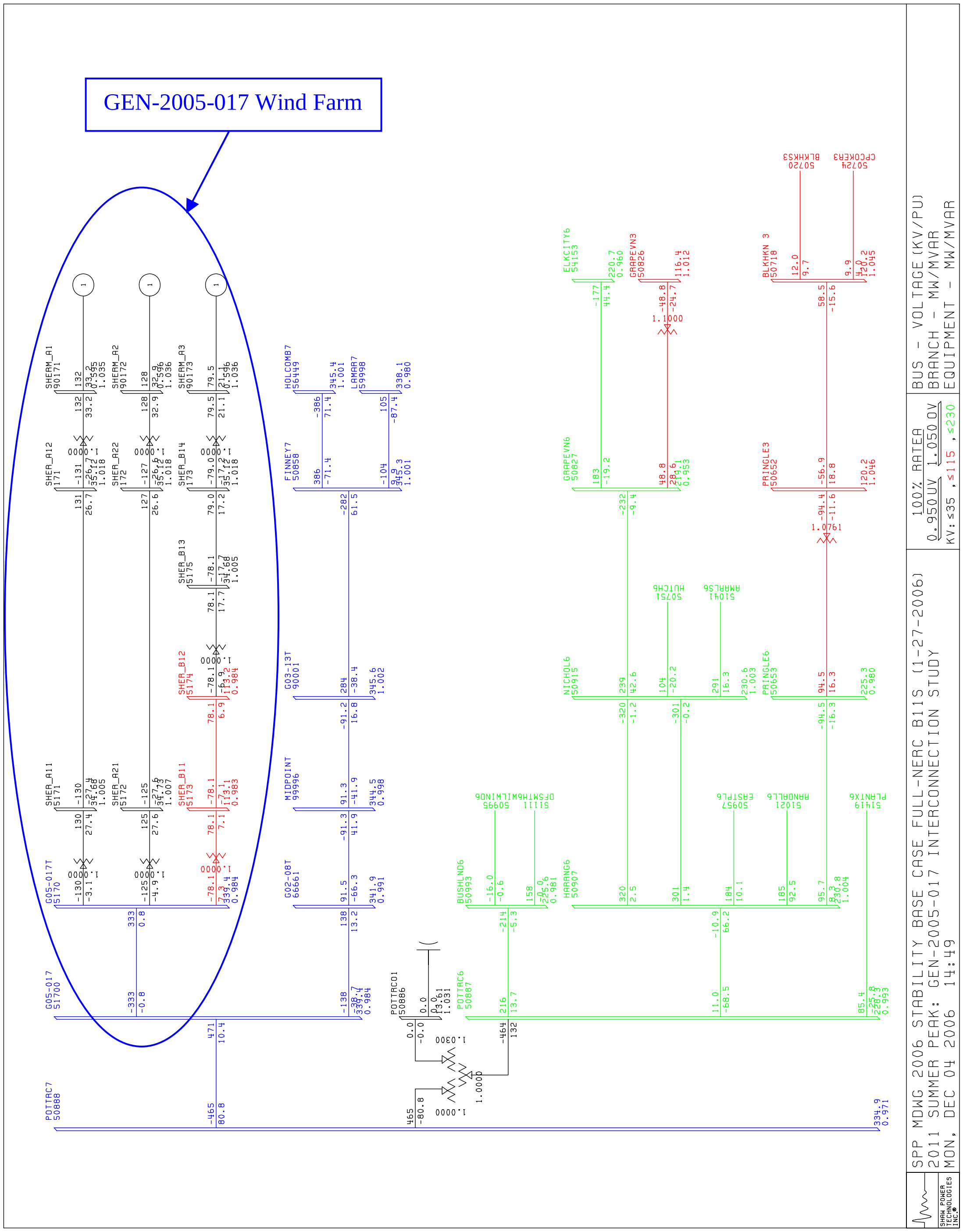

Figure 2-1: Power flow diagram for GEN-2005-017 (Summer Peak 2011)

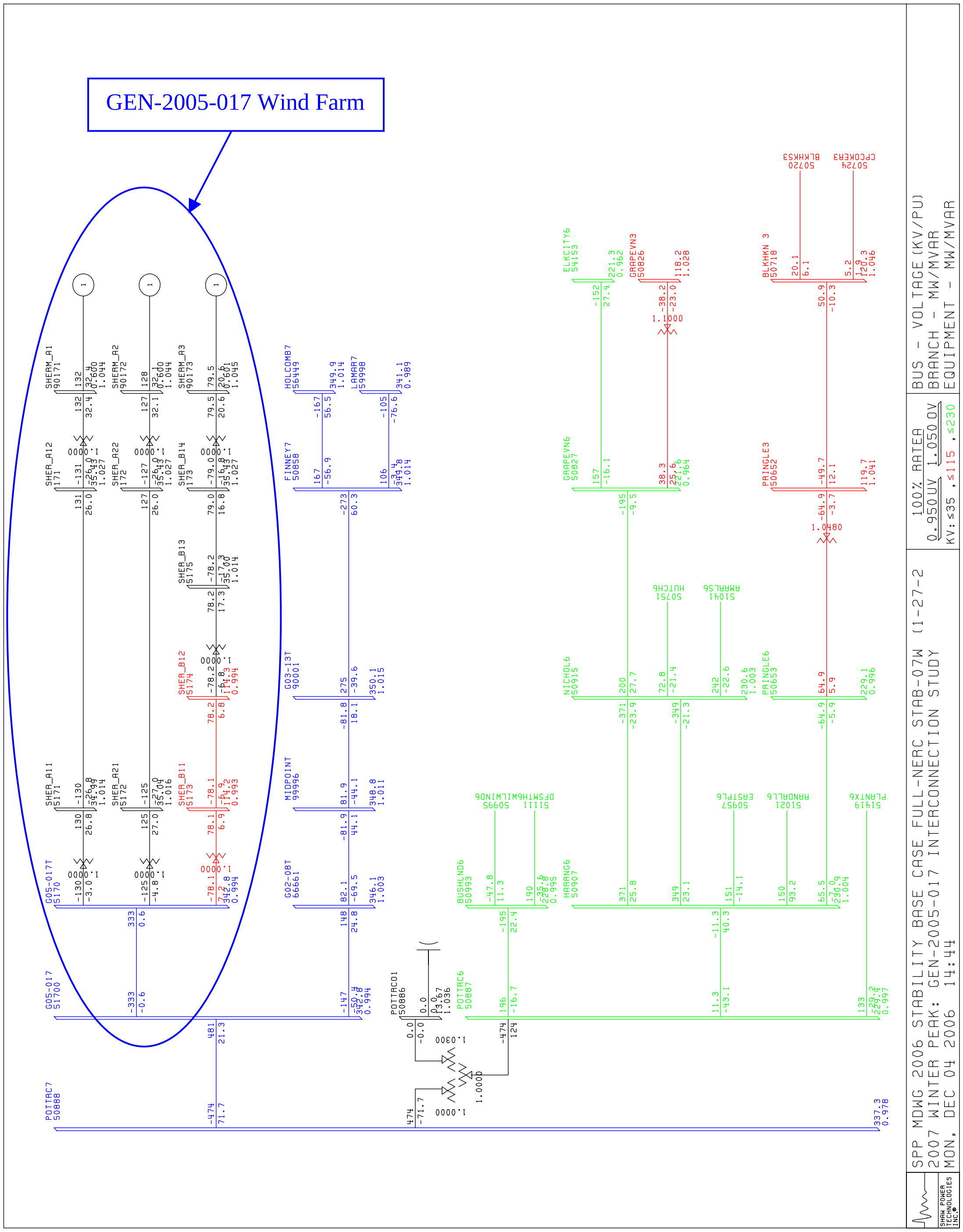

Figure 2-2: Power flow diagram for GEN-2005-017 (Winter Peak 2007)

2.3 STUDY RESULTS

The results for all the disturbances simulated are summarized in Table 2-3.

The plots for all the simulated faults are included in Appendix C.

The results of the simulation indicate that the SPP system will be stable following all the simulated faults in both Summer Peak and Winter Peak system conditions**.**

For both 2007 WP and 2011 SP cases, a 3-phase fault at the interconnection point (FLT_7_3_PH) will cause one group of generators of GEN-2005-017 to be tripped by the undervoltage protection scheme. This fault was repeated with better undervoltage ride-through settings (named with extension "-NT" to the fault ID) as follows:

Default Setting of VTGTPA Model		Changed Trip Settings	
Voltage below 30%	0.02 Sec	Voltage below 15%	0.02 Sec
Voltage below 70%	0.10 Sec	Voltage below 70%	0.625 Sec

With the new undervoltage ride-through settings, GEN-2005-017 remained on-line through the fault and the SPP system was stable following this fault for both 2007 WP and 2011 SP cases.

For both 2007 WP and 2011 SP cases, GEN-2002-08 will be tripped due to low voltage for 3-phase fault on the Potter County to Bushland 230 kV line (FLT_17_3PH) for both pre and post GEN-2005-017 cases. Undervoltage protection trip settings are the cause of the GEN-2002-08 tripping. This is a pre-project condition that is not caused by the addition of GEN-2005-017.

FLT_10_1PH_A, which trips one phase of the faulted line before reclosing, causes numerical problems in PSS/E for the 2011 SP case. FLT_10_1PH_B, which trips all three phases, was added for the 2011 SP case. The SPP system is stable following three-phase line tripping and re-closing, which is a more serious condition than single-phase tripping and re-closing. FLT_10_1PH_A should not cause any problems in realistic system operation.

Table 2-3: Results for Stability Analysis

FAULT	Summer Peak 2011	Winter Peak 2007
FLT_1_3PH	STABLE	STABLE
FLT_2_1PH	STABLE	STABLE
FLT_3_3PH	STABLE	STABLE
FLT_4_1PH	STABLE	STABLE
FLT_5_3PH	STABLE	STABLE
FLT_6_1PH	STABLE	STABLE
FLT_7_3PH	STABLE GEN-2005-017 tripped for Undervoltage (below 30%)	STABLE GEN-2005-017 tripped for Undervoltage (below 30%)
FLT_7_3PH_NT	STABLE	STABLE
FLT_8_1PH	STABLE	STABLE
FLT_9_3PH	STABLE	STABLE
FLT_10_1PH_A	/	STABLE
FLT_10_1PH_B	STABLE	/
FLT_11_3PH	STABLE	STABLE
FLT_12_1PH	STABLE	STABLE
FLT_13_3PH	STABLE	STABLE
FLT_14_1PH	STABLE	STABLE
FLT_15_3PH	STABLE	STABLE
FLT_16_1PH	STABLE	STABLE
FLT_17_3PH	STABLE GEN-2002-08 tripped for Undervoltage (below 75%)	STABLE GEN-2002-08 tripped for Undervoltage (below 75%)
FLT_18_1PH	STABLE	STABLE

2.4 VESTAS MODEL ISSUE

GEN-2002-08 is modeled as Vestas wind turbine generators. The Vestas wind turbine controls in PSS/E include a feature that will move the variable rotor resistance to its maximum value if the voltage goes too low. This has the effect of reducing the reactive power drawn by the induction generator, and thus increasing the voltage. However, for a weak system condition, the voltage may jump up significantly following the reduction in reactive power drawn by the machine. This large increase in voltage will then move the rotor resistance back into variable mode. Thus, the machine reactive power and terminal voltage may jump up and down at a high frequency, producing noise in the plots. This is considered a control instability of the Vestas model, and not a system problem, although it shows up in numerous plots of quantities near GEN-2002-008.

The voltage setting of this control can be changed to eliminate the occurrence of the instability, however with imperfect results. If this voltage setting is set very low (e.g. -1), this feature will not act, which can cause the GEN-2002-008 units to go unstable and trip. If this voltage setting is made very high (e.g. 2), the GEN-2002-008 models will not initialize properly, and they will move significantly during a no-disturbance simulation. However, in either of these cases, the noise in all plots was eliminated. It was decided to leave the GEN-2002-008 model unchanged for the GEN-2005-017 simulations.

Whether or not the implementation of this control is accurate in the PSS/E model is unknown. It is also unknown if this control is adjustable on the real equipment for weaker system conditions. The wind farm developer should consult Vestas and be sure that this issue is addressed by commissioning.

2.5 ADDITIONAL REACTIVE POWER REQUIREMENTS

While the dynamic results show stability for the tested contingencies, selected steady-state contingency analysis of Faults 7 and 9 show the potential for steady-state instability. To remedy this, the GEN-2005-017 generator reactive capability needs to be reserved for contingency conditions. To keep these generators at 1.0 power factor under normal conditions, while also achieving 1.0 power factor at the POI, the following additional capacitors are required:

- 30 MVAR of capacitors at the 34.5 kV bus serving 88 wind turbines
- 30 MVAR of capacitors at the 34.5 kV bus serving 85 wind turbines
- 23 MVAR of capacitors at the 34.5 kV bus serving 53 wind turbines

These capacitors were not assumed in service for the stability simulations.

3 CONCLUSIONS

The objective of this study is to evaluate the impact on system stability after connecting the GEN-2005-017 to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2007 Winter Peak and the 2011 Summer Peak, provided by SPP.

The SPP system will be stable following all the simulated faults with the proposed GEN-2005-017 project in-service.

GEN-2005-017 will be tripped due to low voltage for faults at the interconnection point, assuming the default undervoltage protection trip settings in the PSS/E GE wind turbine model.

With updated low voltage ride-through settings (LVRT II), GEN-2005-017 will stay on-line for faults at the interconnection point and the SPP system will be stable.

GEN-2002-08 will trip due to low voltage for a 3-phase fault on the Potter County to Bushland 230 kV line for both pre and post GEN-2005-017 cases. Undervoltage protection trip settings on the GEN-2002-08 turbines are the cause. This is a pre-project issue not caused by GEN-2005-017.

A total of 83 Mvar of capacitors are required at the GEN-2005-017 34.5 kV buses for steady-state stability purposes.

Based on the results of stability analysis it can be concluded that the proposed GEN-2005-017 project does not adversely impact the stability of the SPP system if the recommended upgrades (LVRT and capacitors) are included.

The results of this analysis are based on available data and assumptions made at the time of conducting this study. If any of the data and/or assumptions made in developing the study model change, the results provided in this report may not apply.

APPENDIX A - WIND FARM MODEL DEVELOPMENT

APPENDIX B - LOAD FLOW AND STABILITY DATA

APPENDIX C - SIMULATION PLOTS FOR STABILITY ANALYSIS