Impact Study for Generation Interconnection Request GEN–2006–049

SPP Tariff Studies
(#GEN-2006-049)

May 6, 2008

Executive Summary

<OMITTED TEXT> (Customer) has requested an Impact Study for the purpose of interconnecting 400 MW of wind generation within the control area of Southwestern Public Service (SPS) primarily located in Seward County, Kansas. The proposed point of interconnection is the 345kV substation proposed to be built for prior queued generation interconnection request GEN-2003-013 on the Potter County – Finney 345kV transmission line owned by Southwestern Public Service (SPS). The proposed in-service date is December 31, 2010. This request is behind a prior queued request to interconnect into the same point. The prior queued request, GEN-2003-013, is for 198 MW.

This study has determined the requirements to interconnect the 400MW of generation is to add a new 345kV ring bus terminal to the switching station to be built for GEN-2003-013. In addition, a new 345kV line from the proposed substation to the Western Farmers Electric Cooperative (WFEC) Mooreland / Oklahoma Gas and Electric (OKGE) Woodward substation, and a new line from the Mooreland/Woodward substation to the OKGE Northwest substation will be required for the interconnection of this wind farm.

A stability study was conducted by ABB Consulting and is included in Attachment 1. The stability study showed that, due to large amount of prior queued generation on the Potter – Finney 345kV line and in the Texas Panhandle on the 115kV and 230kV system, the interconnection could not be accommodated without the addition of the two 345kV lines. The powerflow analysis was then performed again with the two 345kV lines to Mooreland in service. These results are included within this report.

This study assumed that the 345kV line from GEN-2006-044 to Mooreland / Woodward which has been assigned to GEN-2006-044 is in service. This study assumed that all of the proposed Expansion Plan projects to be terminated at the Hitchland substation are in service.

The total minimum costs for interconnection are estimated at $160,000,000. These costs are listed in Table 2.

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.

Introduction

<OMITTED TEXT> (Customer) has requested an Impact Study for the purpose of interconnecting 400 MW of wind generation within the control area of Southwestern Public Service (SPS) primarily located in Stevens County, Kansas. The proposed point of interconnection is the 345kV substation proposed to be built for prior queued generation interconnection request GEN-2003-013 on the Potter County – Finney 345kV transmission line owned by Southwestern Public Service (SPS). The proposed in-service date is December 31, 2010. This request is behind a prior queued request to interconnect into the same point. The prior queued request, GEN-2003-013, is for 198 MW.

Interconnection Facilities

The Customer has requested interconnecting a 400 MW wind farm within the control area of Southwestern Public Service Company (d/b/a Xcel Energy) (SPS). The plant site is located in Seward County, Kansas and will be interconnected into the proposed 345kV substation to be built for interconnection request GEN-2003-013. This substation is to be located along the Potter County – Finney 345kV transmission line. The proposed method of interconnection is to add a new 345kV terminal into this substation.

The Impact study has determined that adding a fourth 345kV terminal to the proposed GEN-2003-013 substation will not be adequate for interconnecting the 400 MW of wind generation. All SPS Expansion Planning projects in the area of Hitchland were included. The Hitchland – Woodward 345kV transmission line which has been assigned to GEN-2006-044 was included. Generator and voltage instability are encountered for certain contingencies that were studied in the analysis.

Therefore, the interconnection of GEN-2006-049 will require the addition of two additional 345kV transmission lines to the east. For this study, a 345kV transmission line from GEN-2003-013 to the Mooreland / Woodward substation and a 345kV transmission line from the Mooreland / Woodward to Northwest substation were added and the results analyzed. The analysis has indicated that stability issues will be alleviated with the addition of these 345kV transmission lines. Therefore, GEN-2006-049 interconnection Customer is responsible for the addition of these transmission lines.

The Mooreland/Woodward – Northwest 345kV transmission line has since been announced as a planned project by Oklahoma Gas and Electric with an in service date of approximately June, 2010. Therefore, at this time, it is not anticipated that the Customer will be responsible for the construction of this transmission line. The 345kV line from GEN-2003-013 to Mooreland / Woodward is necessary because of the addition of GEN-2006-049. Therefore, the Customer is responsible for the cost of this line. The approximate distance from GEN-2003-013 to Mooreland is estimated at 160 miles. With necessary substation construction, the line and substation work is estimated to cost approximately $160,000,000. This estimate will be refined during the course of a Facility Study if the Customer wishes to execute the Facility Study Agreement.

There are also several other facilities that are assumed to be in service for the interconnection of this request. These facilities are listed in the powerflow analysis section. If any of these facilities are not constructed or previous queued projects drop out of the queue, this request will need to be restudied.

The Impact Study has determined the reactive compensation requirements of the GEN-2006-049 wind farm. With the Customer requested Suzlon S88 2.1 MW wind turbines, the wind farm will be required to install three (3) capacitor banks with a total of 35.4 Mvar.

The banks will include three (3) 34.5kV kV capacitor banks on the low side of the Customer 115/34.5kV transformers sized at 13.2 Mvar, 12.7 Mvar, and 9.5 Mvar

The Impact Study has also determined that with the Suzlon wind turbines, the required capacitor banks, and the 345kV transmission line to Mooreland in service, GEN-2006-049 will meet FERC Order #661A low voltage requirements for low voltage ride through.

Table 1. Interconnection Facilities

FACILITY	ESTIMATED COST (2008 DOLLARS)
CUSTOMER – 345/34.5 kV collector substation facilities.	*
CUSTOMER – (3) 345/34.5 kV transformers and all related 345/34.5 kV switching equipment located at the Customer 345/34.5 kV switching station.	*
CUSTOMER – (1) 345 kV ties between Customer 345/34.5 kV switching station and the point of interconnection.	*
CUSTOMER – Right-of-Way for Customer facilities.	*
CUSTOMER – Three (3) 34.5 kV banks sized at 13.2Mvar, 12.7 Mvar, and 9.5Mvar.	*
TOTAL	*

* Determined by Customer

Table 2. Network Upgrades

FACILITY	ESTIMATED COST (2008 DOLLARS)
Various Transmission Owners - Add (2) 345 kV terminals to the GEN-2003-013 switching station; Add substation terminals at Woodward substation; build 160 miles of 345kV line to OKGE Woodward substation.	**$160,000,000**
TOTAL	**$160,000,000**

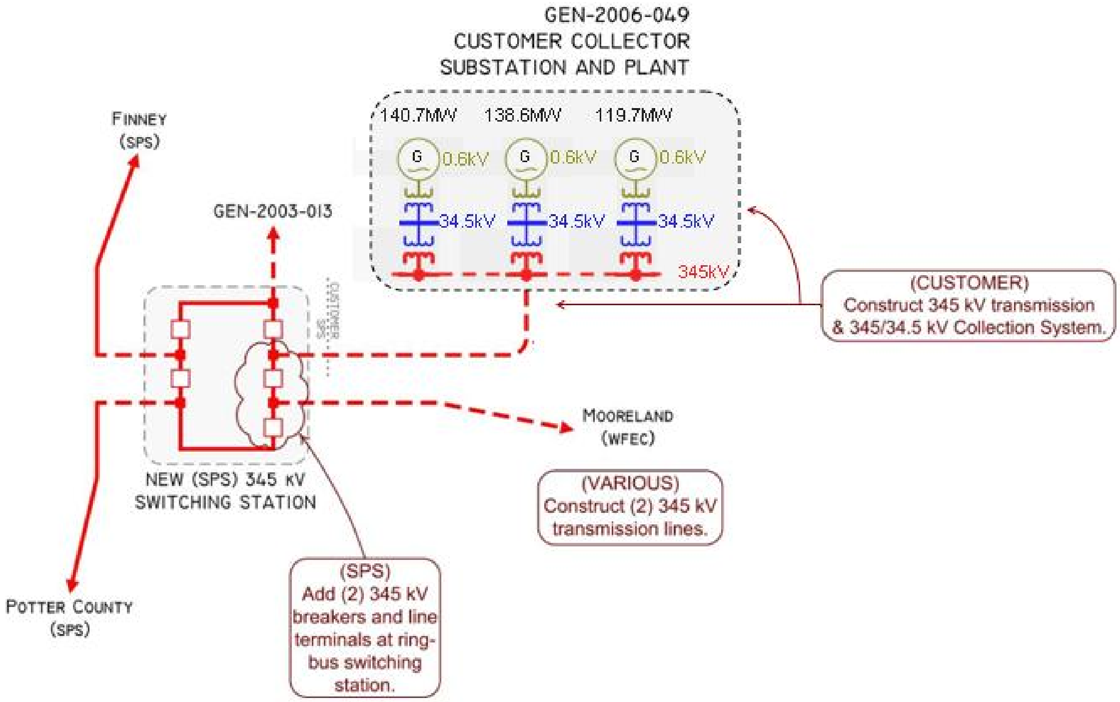

Figure 1. Proposed Interconnection Configuration
(Final design to be determined)

Powerflow Analysis

A powerflow analysis was conducted for the facility using modified versions of the 2009 and 2012 summer and winter peak, and 2017 summer peak models. The output of the Customer's facility was offset in each model by a reduction in output of existing online SPP generation. This method allows the request to be studied as an Energy Resource (ER) Interconnection request. The proposed in-service date of the generation is December 31, 2010. The available seasonal models used were through the 2017 Summer Peak of which is the end of the current SPP planning horizon.

The analysis of the Customer's project indicates that, given the requested generation level of 400 MW and location, additional criteria violations will occur on the existing OKGE, SPS, Sunflower Electric (SUNC), West Plains Energy (WEPL), and WFEC transmission systems under steady state and contingency conditions in the peak seasons. These network constraints are shown in Table 3.

In Table 4, a value of Available Transfer Capability (ATC) associated with each overloaded facility is included. These values may be used by the Customer to determine lower generation capacity levels that may be installed. When transmission service associated with this interconnection is evaluated, the loading of the facilities listed in this table may be greater due to higher priority reservations. When a facility is overloaded for more than one contingency, only the highest loading on the facility for each season is included in the table.

There are several other proposed generation additions in the general area of the Customer's facility. Some of the local projects that were previously queued were assumed to be in service in this Impact Study. Those local projects that were previously queued and have advanced to nearly complete phases were included in this Impact Study.

This analysis assumed that the following projects were built and in service

- GEN-2003-013 – Mooreland / Woodward 345kV line (assigned to GEN-2006-049)
- Mooreland / Woodward – Northwest 345kV transmission line (OG&E has announced construction but could be assigned to GEN-2006-049 if OG&E does not construct)
- Hitchland – Mooreland / Woodward 345kV line (assigned to GEN-2006-044)
- SPP Transmission Expansion Planning Projects in the Hitchland area (SPP Base Plan Funded for 6/1/2010 in service)
    - Hitchland - 345/230kV autotransformer
    - Hitchland – 230/115kV autotransformer
    - Hitchland – Perryton 230kV transmission line
    - Hitchland – Pringle 230kV transmission line
    - Hitchland – Moore County 230kV transmission line
    - Sherman County – Texas County 115kV line routed into Hitchland 115kV
    - Hansford County – Texas County 115kV line routed into Hitchland 115kV

If any of these projects do not get constructed or if any prior queued generation interconnection request withdraws from the queue, this analysis will need to be re-evaluated.

Powerflow Analysis Methodology

The Southwest Power Pool (SPP) criteria states that: “The transmission system of the SPP region shall be planned and constructed so that the contingencies as set forth in the Criteria will meet the applicable *NERC Planning Standards* for System Adequacy and Security – Transmission System Table I hereafter referred to as NERC Table I) and its applicable standards and measurements”.

Using the created models and the ACCC function of PSS\E, single contingencies in portions or all of the modeled control areas of Sunflower Electric Power Corporation (SUNC), Missouri Public Service (MIPU), Westar (WESTAR), Kansas City Power & Light (KCPL), West Plains (WEPL), Midwest Energy (MIDW), Oklahoma Gas and Electric (OKGE), American Electric Power West (AEPW), Grand River Dam Authority (GRDA), Southwestern Public Service (SPS), Western Farmers Electric Cooperative (WFEC), Western Resources (WERE), and other control areas were applied and the resulting scenarios analyzed. This satisfies the ‘more probable’ contingency testing criteria mandated by NERC, and the SPP criteria.

Table 3: Network Constraints

AREA	OVERLOADED ELEMENT
OKGE	NORTHWEST (NORTWST2) 345/138/13.8KV TRANSFORMER CKT 1
OKGE/WFEC	GLASS MOUNTAIN - MOORELAND 138KV CKT 1
SPS	HARRINGTON STATION - NICHOLS STATION 230KV CKT 1
SPS	HARRNG_MID6 230.00 - NICHOLS STATION 230KV CKT 2
SUNC/WEPL	SPEARVILLE (SPEARVL) 345/230/13.8KV TRANSFORMER CKT 1
WEPL	MEDICINE LODGE - SUN CITY 115KV CKT 1
WFEC	MOORLND 345.00 345/138KV TRANSFORMER CKT 1
OKGE	Oklahoma Gas and Electric
SPS	Southwestern Public Service Company
SUNC	Sunflower Electric
WEPL	West Plains Energy
WFEC	Western Farmers Electric Cooperative

Table 4: Contingency Analysis

SEASON	OVERLOADED ELEMENT	RATING (MVA)	LOADING (%)	ATC (MW)	CONTINGENCY
09WP	GLASS MOUNTAIN - MOORELAND 138KV CKT 1	124	125	0	MOORLND 345.00 - NORTHWEST 345KV CKT 1
09WP	MOORLND 345.00 345/138KV TRANSFORMER CKT 1	448	124	21	MOORLND 345.00 - NORTHWEST 345KV CKT 1
09WP	SPEARVILLE (SPEARVL) 345/230/13.8KV TRANSFORMER CKT 1	336	105	275	MOORLND 345.00 - NORTHWEST 345KV CKT 1
12SP	HARRINGTON STATION - NICHOLS STATION 230KV CKT 1	635	113	0	HARRNG_MID6 230.00 - NICHOLS STATION 230KV CKT 2
12SP	HARRNG_MID6 230.00 - NICHOLS STATION 230KV CKT 2	635	113	0	HARRINGTON STATION - NICHOLS STATION 230KV CKT 1
12SP	NORTHWEST (NORTWST2) 345/138/13.8KV TRANSFORMER CKT 1	493	106	0	NORTHWEST (NORTWST3) 345/138/13.8KV TRANSFORMER CKT 1
12SP	GLASS MOUNTAIN - MOORELAND 138KV CKT 1	124	119	24	MOORLND 345.00 - NORTHWEST 345KV CKT 1
12SP	SPEARVILLE (SPEARVL) 345/230/13.8KV TRANSFORMER CKT 1	336	109	153	MOORLND 345.00 - NORTHWEST 345KV CKT 1
12SP	MOORLND 345.00 345/138KV TRANSFORMER CKT 1	448	110	225	MOORLND 345.00 - NORTHWEST 345KV CKT 1
12SP	MEDICINE LODGE - SUN CITY 115KV CKT 1	79	106	260	MULLERGREN - SPEARVILLE 230KV CKT 1
12WP	GLASS MOUNTAIN - MOORELAND 138KV CKT 1	124	120	0	MOORLND 345.00 - NORTHWEST 345KV CKT 1
12WP	MOORLND 345.00 345/138KV TRANSFORMER CKT 1	448	125	1	MOORLND 345.00 - NORTHWEST 345KV CKT 1
12WP	SPEARVILLE (SPEARVL) 345/230/13.8KV TRANSFORMER CKT 1	336	103	311	MOORLND 345.00 - NORTHWEST 345KV CKT 1
17SP	NORTHWEST (NORTWST2) 345/138/13.8KV TRANSFORMER CKT 1	493	110	0	NORTHWEST (NORTWST3) 345/138/13.8KV TRANSFORMER CKT 1
17SP	GLASS MOUNTAIN - MOORELAND 138KV CKT 1	124	112	157	MOORLND 345.00 - NORTHWEST 345KV CKT 1
17SP	MOORLND 345.00 345/138KV TRANSFORMER CKT 1	448	105	319	MOORLND 345.00 - NORTHWEST 345KV CKT 1
17SP	NORTHWEST (NORTWST3) 345/138/13.8KV TRANSFORMER CKT 1	493	101	325	NORTHWEST (NORTWST2) 345/138/13.8KV TRANSFORMER CKT 1

Note: When transmission service associated with this interconnection is evaluated, the loading of the facilities listed in this table may be greater due to higher priority reservations. If the loading of a facility is higher, the level of ATC will be lower.

Stability Analysis

A transient stability analysis was conducted for the facility by ABB Consulting (ABB). The study is attached to this report. The stability analysis indicated that the Suzlon turbines at both GEN-2006-049 and GEN-2006-044 will have uncontrollable oscillations for an outage of the Finney – Holcomb 345kV transmission line with all prior queued projects in the Texas Panhandle in service. Additional transmission lines are required for the interconnection of this generation interconnection request.

This analysis assumed that the following projects were built and in service

- GEN-2003-013 – Mooreland / Woodward 345kV line (assigned to GEN-2006-049)
- Mooreland / Woodward – Northwest 345kV transmission line (OG&E has announced construction but could be assigned to GEN-2006-049 if OG&E does not construct)
- Hitchland – Mooreland / Woodward 345kV line (assigned to GEN-2006-044)
- SPP Transmission Expansion Planning Projects in the Hitchland area (SPP Base Plan Funded for 6/1/2010 in service)
    - Hitchland - 345/230kV autotransformer
    - Hitchland – 230/115kV autotransformer
    - Hitchland – Perryton 230kV transmission line
    - Hitchland – Pringle 230kV transmission line
    - Hitchland – Moore County 230kV transmission line
    - Sherman County – Texas County 115kV line routed into Hitchland 115kV
    - Hansford County – Texas County 115kV line routed into Hitchland 115kV

If any of these projects do not get constructed or if any prior queued generation interconnection request withdraws from the queue, this analysis will need to be re-evaluated.

Attachment 1. Stability Study

POWER SYSTEMS DIVISION
GRID SYSTEMS CONSULTING

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2006-049

FINAL REPORT

REPORT NO.: 2008-11629-R0
Issued: May 6, 2008

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ABB Inc – Grid Systems Consulting **Technical Report**

Southwest Power Pool	**No.** 2008-11629-R0	
Impact Study for Generation Interconnection request GEN-2006-049	5/6/2008	# Pages 27

Author(s):	**Reviewed by:**	**Approved by:**
Ashish Jain Sunil Verma	Bill Quaintance	Willie Wong

Executive Summary

Southwest Power Pool (SPP) has a commissioned ABB Inc. to perform a generator interconnection study for a 345 kV interconnection of a 400 MW wind farm in Stevens County, Kansas. This wind farm will be interconnected into a proposed 345kV switching station on the Potter – Finney 345kV line. The proposed station is to be built for generation interconnection request GEN-2003-013. This transmission line is owned by Southwestern Public Service (d/b/a Xcel Energy). As per the developer's request, the 400 MW of additional generation was studied assuming Suzlon S88 2.1 MW wind turbines. Faults were simulated on the SPP system for Winter Peak 2008 and Summer Peak 2012 conditions.

The system was unstable for a critical fault near the POI after interconnection of the proposed project. The same fault was stable in the pre-project cases. Two upgrade options were studied for GEN-2006-049 interconnection.

Option-1: Stable performance was found after the concurrent addition the following facilities:

1. *MOORLAND - NORTHWEST 345 KV LINE -1*
2. *MOORLAND - NORTHWEST 345 KV LINE -2*
3. *MOORLAND - HITCHLAND 345 KV LINE -2*
4. *SVC - 100 MVA at bus # 66661*

Option-2: Addition of 345KV CKT #1 FROM GEN-2006-049 TO MOORELAND. All tested faults were stable after this upgrade. Option 2 is the preferred upgrade due to its expected lower cost.

Rev No.	Revision Description	Date	Authored by	Reviewed by	Approved by
0	Draft Report	5/6/2008	Ashish Jain Sunil Verma	Bill Quaintance	Willie Wong
DISTRIBUTION: Charles Hendrix – Southwest Power Pool					

With Option 2, the reactive power requirements to achieve unity power factor at the POI are 13.2, 12.7, and 9.5 Mvar at the three 34.5 kV substation buses, respectively, for a total of 35.4 Mvar.

FERC Order 661A Compliance – With the new 345 kV line from GEN-2006-049 station to Mooreland, the GEN-2006-049 wind farm with Suzlon 2.1 MW turbines complies with the latest FERC order on low voltage ride through for wind farms. With this arrangement, the wind farm would not trip off line by voltage relay actuation for local faults near the POI.

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.

TABLE OF CONTENTS

1 INTRODUCTION

SPP has commissioned ABB Inc. to perform an interconnection impact study for a 400 MW wind farm in Stevens County, Kansas. This wind farm will be interconnected into a proposed 345kV switching station on the Potter – Finney 345kV line. The proposed station is to be built for generation interconnection request GEN-2003-013. This transmission line is owned Southwestern Public Service (d/b/a Xcel Energy). 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 additional 400 MW wind farm to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios, 2008 Winter Peak and the 2012 Summer Peak, provided by SPP. Figure 1-1 shows the location of the proposed 400 MW wind farm interconnecting station and Figure 1-2 shows a one-line of the proposed interconnection with the existing network.

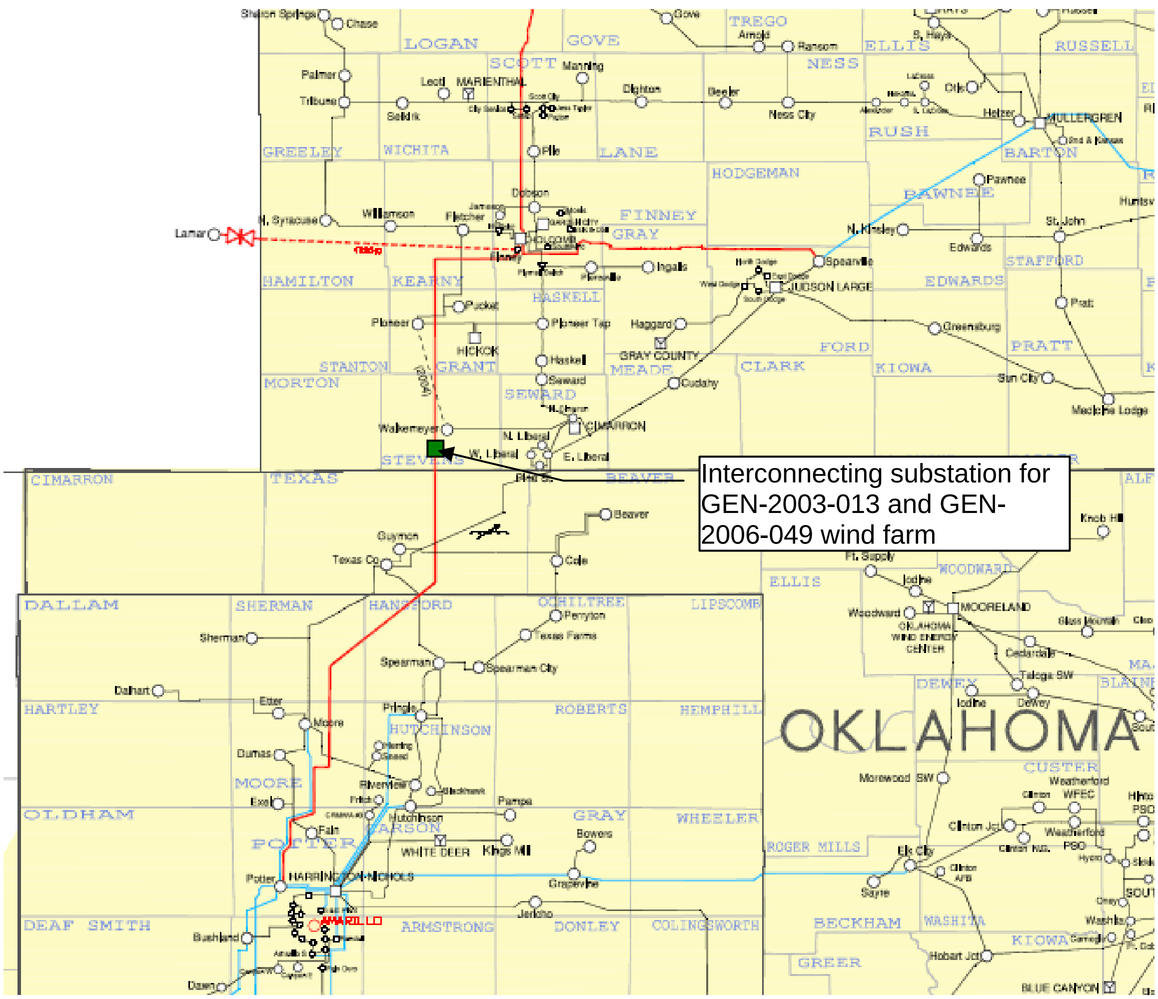

Figure 1-1 Wind farm GEN-2003-013 and GEN-2006-049 interconnecting substation

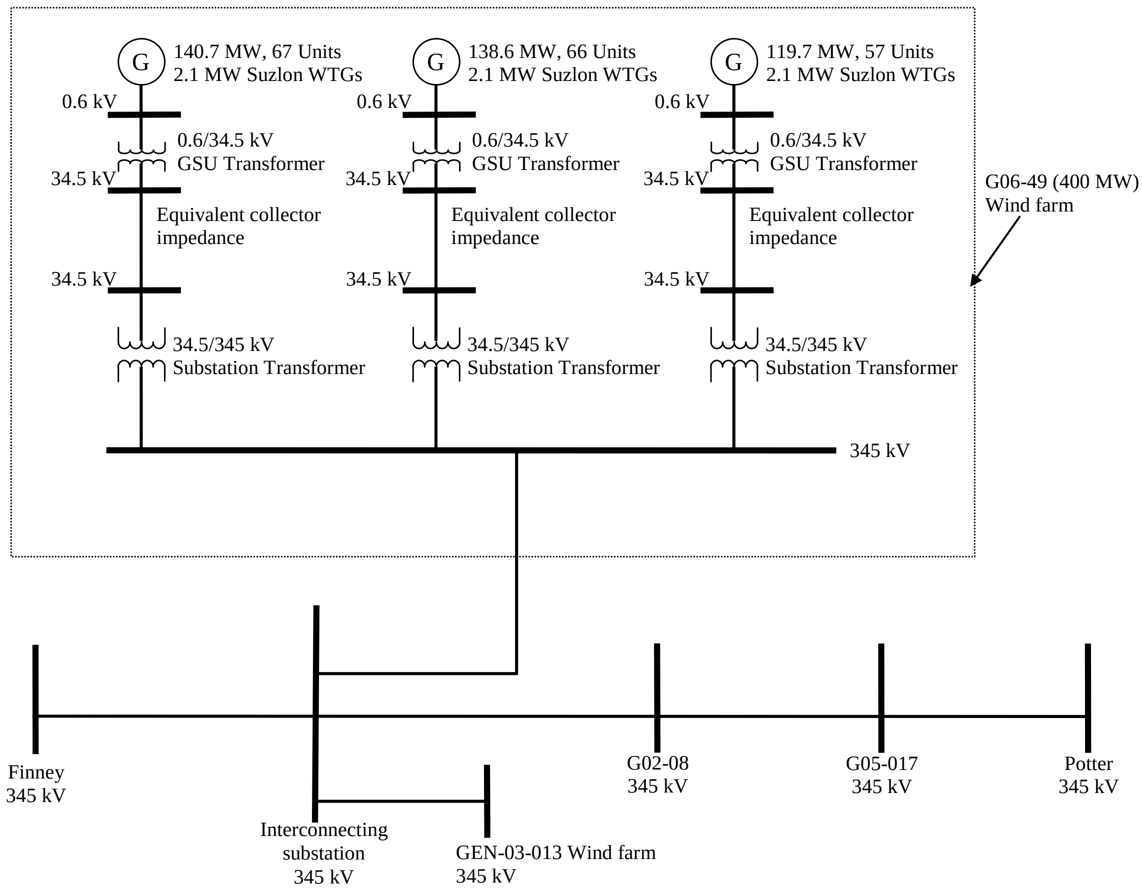

Figure 1-2 Proposed 400 MW wind farm interconnection

2 STABILITY ANALYSIS

In this stability study, ABB investigated the stability of the system for a series of faults specified by SPP, which are in the vicinity of the proposed plant. Three-phase and single-line-to-ground (SLG) faults with reclosing in the vicinity of the proposed project were considered.

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."

In addition, new wind generators (which are usually asynchronous) are required to stay on-line following normally cleared faults at the Point of Interconnection (POI).

Stability analysis was performed using Siemens-PTI's PSS/E™ dynamics program V30.2.1. 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. Stability of asynchronous machines was monitored as well.

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.

The ability of the wind generators to stay connected to the grid during the disturbances and during the fault recovery was monitored. This is primarily determined by their low-voltage ride-through capabilities, or lack thereof, as represented in the models by low-voltage trip settings.

2.2 STUDY MODEL DEVELOPMENT

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

Pre-Project Power Flow Case

The interconnection request ahead of GEN-2006-049 and in the same general area is GEN-2006-044. The impact study for GEN-2006-044 was also performed by ABB. The final post-project cases from that study, including required transmission upgrades, were used as the pre-project power flow cases for this GEN-2006-049 impact study. These cases represent the projected 2008 Winter Peak and 2012 Summer Peak load levels and system conditions.

PSS/E one-line diagrams of pre-project power flow cases are shown in Figure 2-1 and Figure 2-2.

GEN-2006-049 Wind Farm Power Flow Model

The GEN-2006-049 wind farm will consist of 190 Suzlon 2.1 MW wind turbine generators that will be split among three different substation transformers, which are connected to a single 345 kV substation. The 190 turbines are modeled as three equivalents as follows:

- Equivalent-1: Representing 67 Suzlon 2.1 MW wind turbine generators connected to the 345 kV bus through a substation transformer, equivalent collector impedance, and GSU transformer.
- Equivalent-2: Representing 66 Suzlon 2.1 MW wind turbine generators connected to the 345 kV bus through a substation transformer, equivalent collector impedance, and GSU transformer.
- Equivalent-3: Representing 57 Suzlon 2.1 MW wind turbine generators connected to the 345 kV bus through a substation transformer, equivalent collector impedance, and GSU transformer.

See Figure 2-3. These equivalent generators are connected to equivalent 34.5 kV collector systems through equivalent generator step-up transformers (one equivalent transformer 0.60/34.5 kV for each equivalent generator). Each of the three 34.5/345 kV collector station transformers is explicitly modeled.

The 345 kV wind farm substation is connected to the POI via single 345 kV line. The detailed process of wind farm model development is described in Appendix A.

All three collector systems include reactive power compensation individually at their 34.5 kV collector station buses to maintain unity power factor at the POI. The exact Mvar levels vary with each tested post-project scenario. The final compensation requirements are reported below with the final interconnection solution.

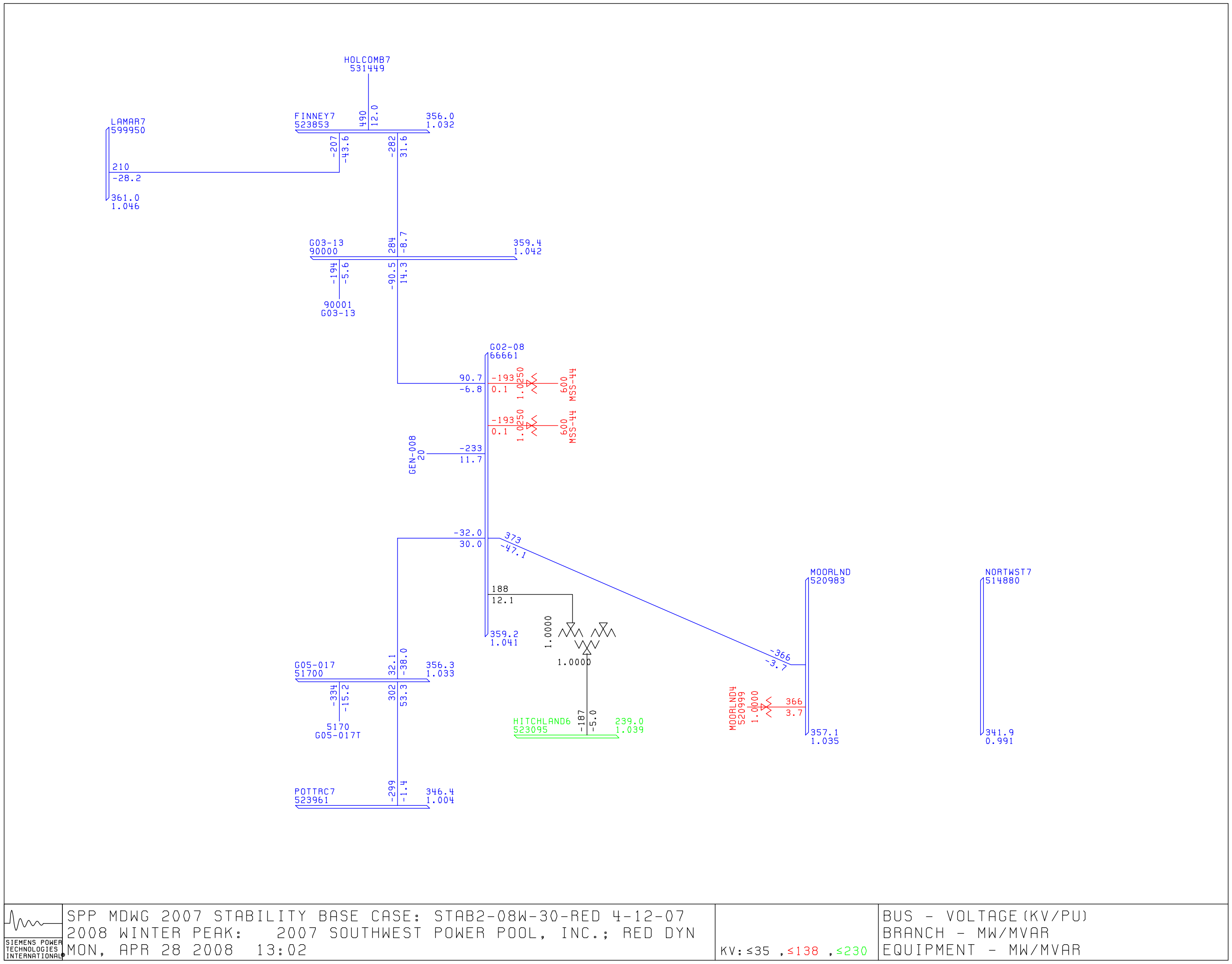

Figure 2-1 Final 2008 Winter Peak Case without GEN-2006-049

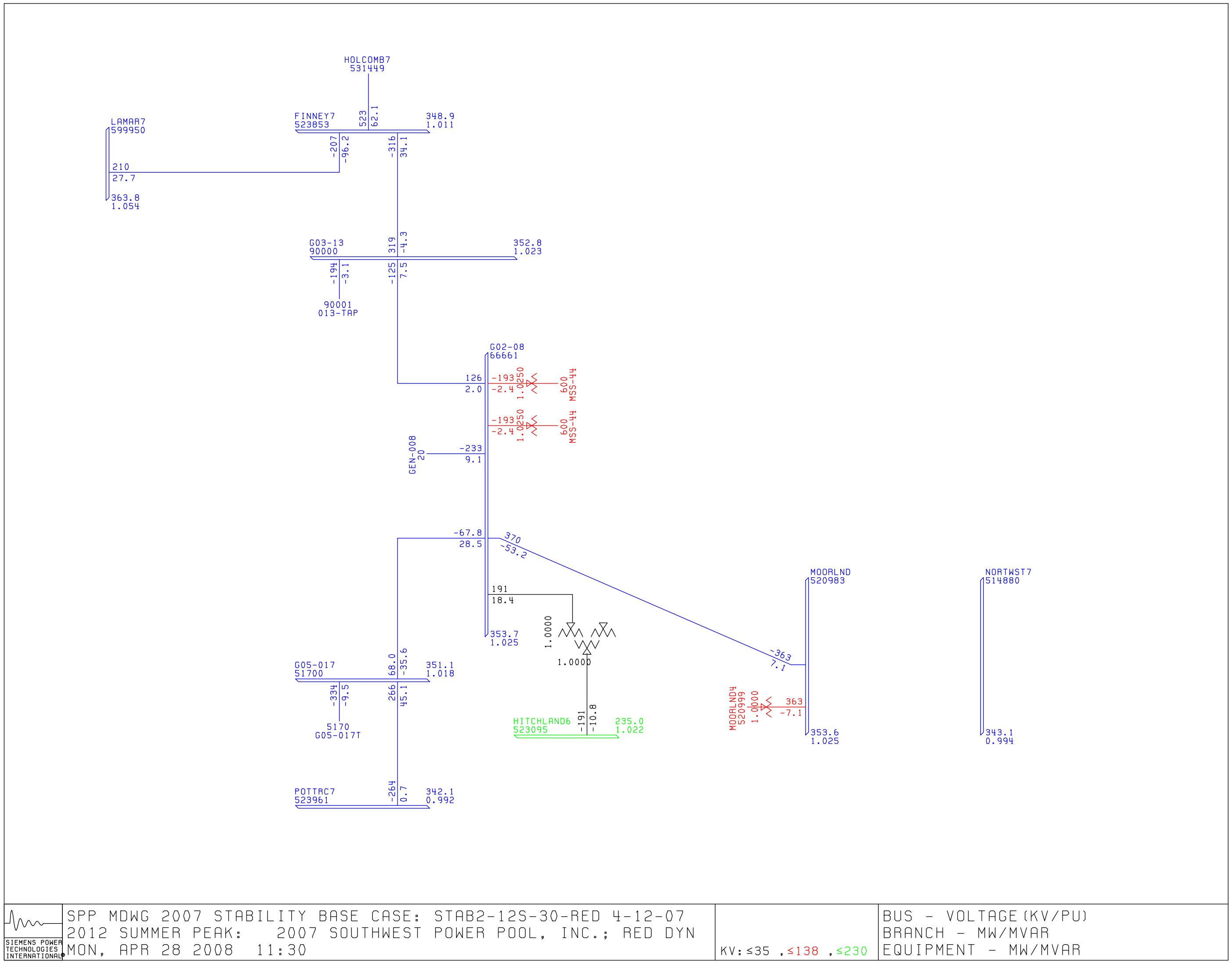

Figure 2-2 Final 2012 Summer Peak Case without GEN-2006-049

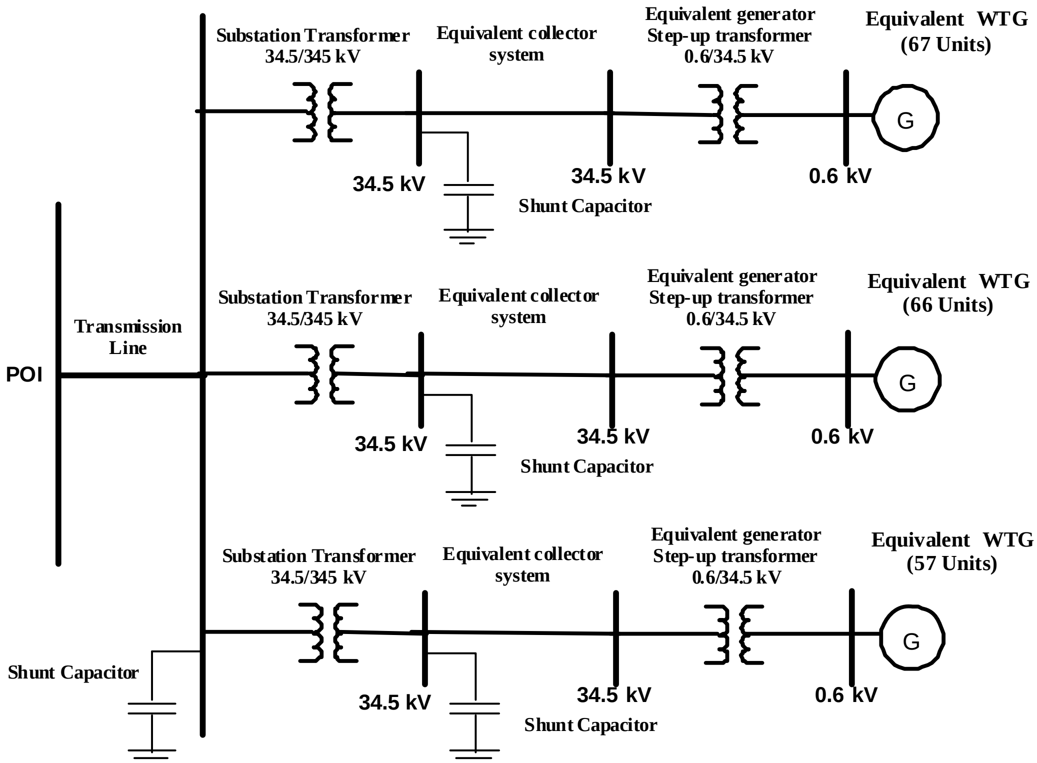

Figure 2-3 GEN-2006-049 Model One-line Diagram

Post-Project Dispatch

The GEN-2006-049 request is for the interconnection of 400 MW of wind-powered generation. The plant will connect to the Potter–Finney 345 kV transmission line at the bus #90000. To balance the additional 400 MW of generation, prior-queued and existing generation was scaled down in areas 502, 524, 525, 536, 540, 541, and 544, as shown in Table 2-1. Thus two power flow cases with GEN-2006-049 were established:

- Gen-2006-049_WP.SAV – a 2008 winter peak case
- Gen-2006-049_SP.SAV – a 2012 summer peak case

Figure 2-4 and Figure 2-5 show the one-line diagrams for the local area with the wind farm for 2008 Winter Peak and 2012 Summer Peak respectively.

Table 2-1: GEN-2006-049 project details

System condition	MW	Location	Point of Interconnection	Sink
Winter Peak	400	Steven County, Kansas	Substation at Potter – Finney 345kV line (#90000)	Areas 502, 524, 525, 536, 540, 541, 544
Summer Peak	400	Steven County, Kansas	Substation at Potter – Finney 345kV line (#90000)	Areas 502, 524, 525, 536, 540, 541, 544

Stability Database

The post-project stability models from the GEN-2006-044 study were used as the pre-project stability models for this study. These files are compatible with PSS/E version 30.2.1.

The stability data for GEN-2006-049 was appended to the Pre-project data. The dynamic model provided for the Suzlon S88 wind turbines is called S88001. The provided object code file is called "S88001_MODEL_60_V201_V30.OBJ". This model was used for each of the three equivalent generators. The voltage trip settings included in this model are shown in Table 2-2.

Table 2-2: Suzlon S88001 Voltage Trip Settings

V (pu)	time (s)
1.20	0.08
1.15	60.00
0.90	60.00
0.80	2.80
0.60	1.60
0.40	0.70
0.15	0.08

The PSS/E power flow and stability model data for GEN-2006-049 are included in Appendix B.

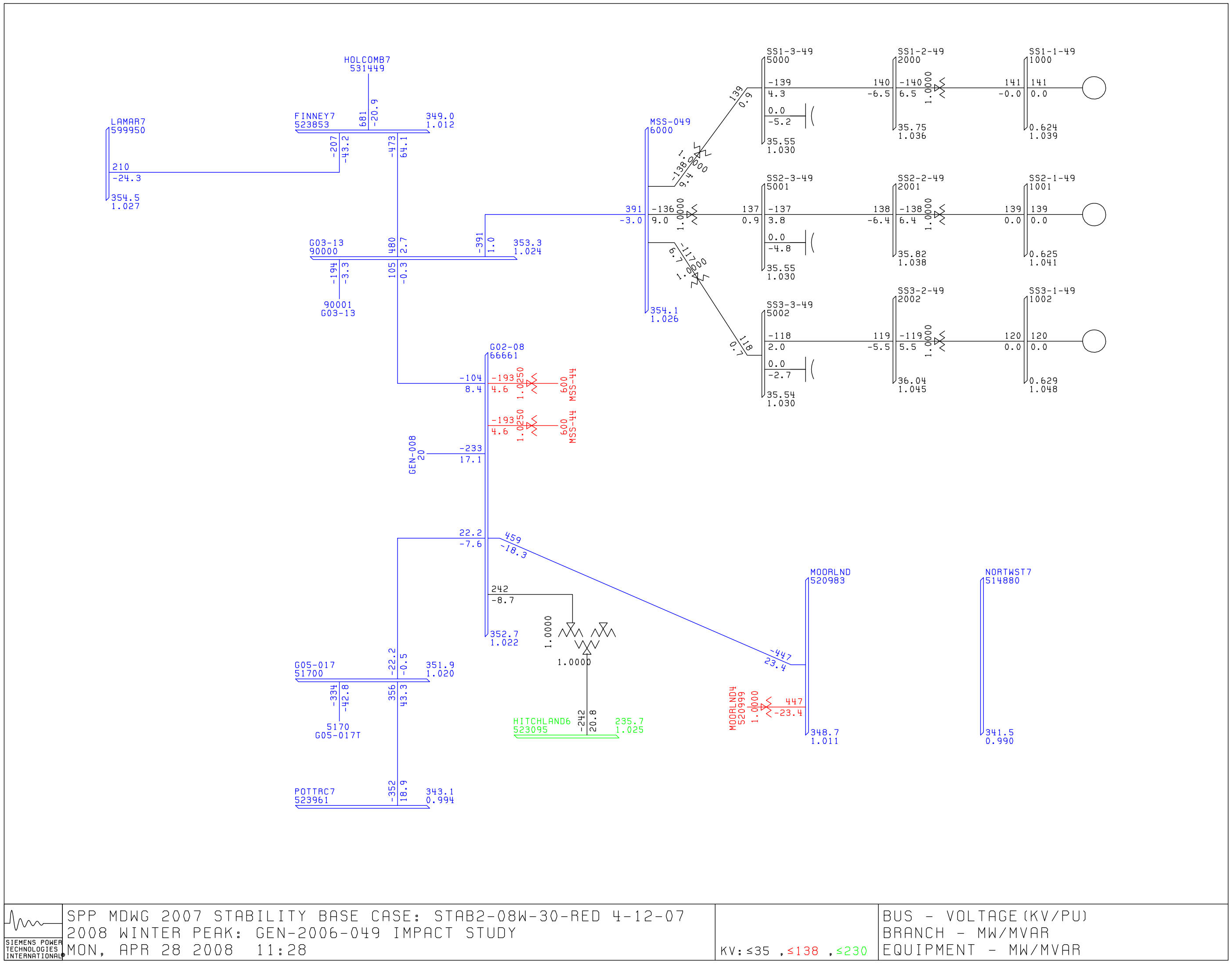

Figure 2-4 2008 Winter Peak Case with GEN-2006-049

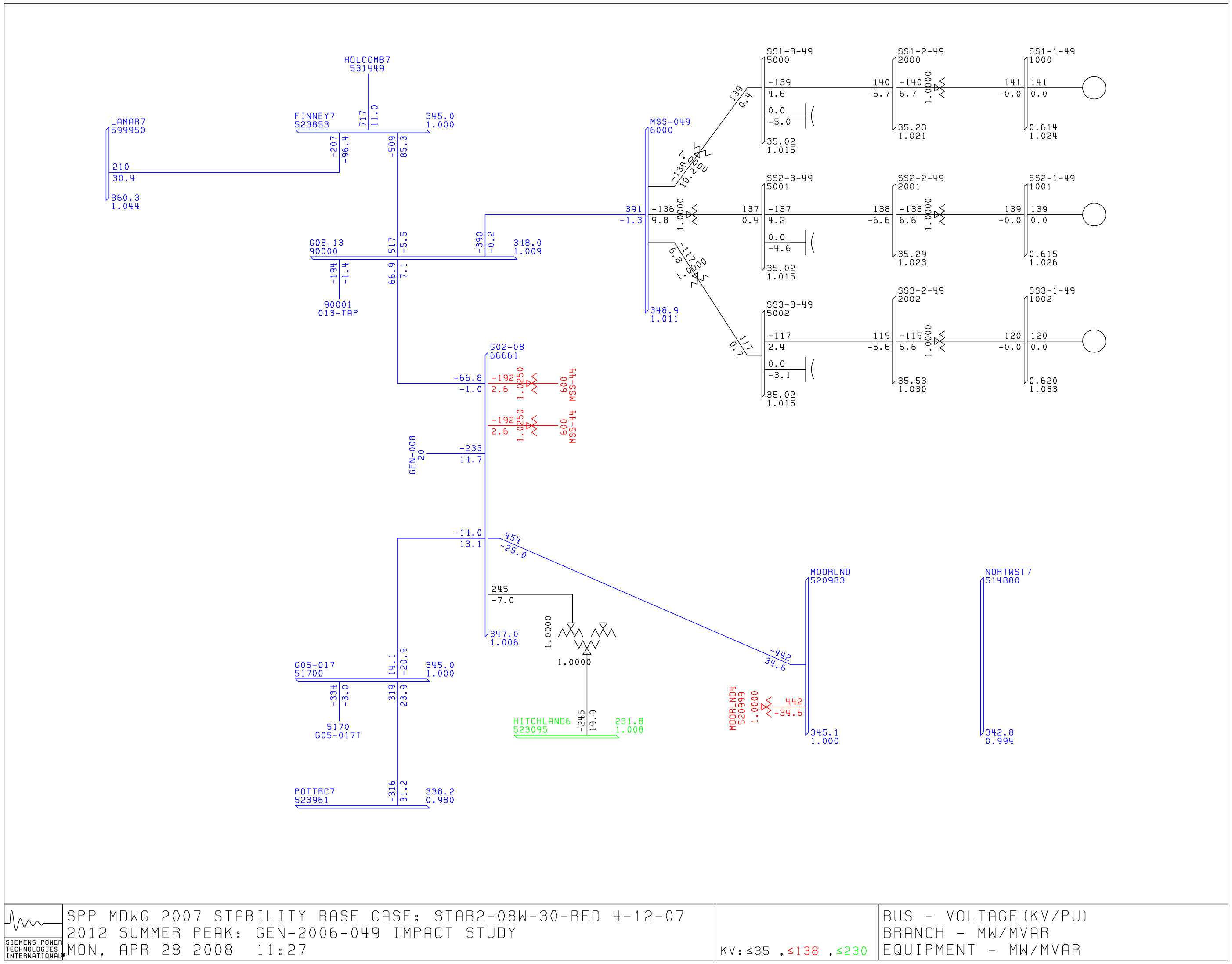

Figure 2-5 2012 Summer Peak Case with GEN-2006-049

Simulated Disturbances

Table 2-3 lists the faults simulated for stability analysis.

Table 2-3 List of Faults for Stability Analysis

FAULT	FAULT DESCRIPTION
FLT_1_3PH	a. Apply 3-phase fault at the GEN-2003-013 bus (90000). b. Clear fault after 4 cycles by removing the line from GEN-2003-013 to Finney 345kV (523853 to 90000).
FLT_2_1PH	a. Apply 1-phase fault at the GEN-2003-013 bus (90000). b. Clear fault after 4 cycles by tripping the line from GEN-2003-013 to Finney 345kV (523853 to 90000). c. Wait 30 cycles, and then re-close the phase in (b) into the fault. d. Apply fault for 4 cycles, then trip the line in (b), and remove fault.
FLT_3_3PH	a. Apply 3-phase fault at the GEN-2003-013 bus (90000). b. Clear fault after 4 cycles by removing the line from GEN-2003-013 to GEN-2002-008 345kV (66661 – 90000).
FLT_4_1PH	a. Apply 1-phase fault at the GEN-2003-013 bus (90000). b. Clear fault after 4 cycles by tripping the line from GEN-2003-013 – GEN-2002-008 345kV (66661 to 90000). c. Wait 20 cycles, and then re-close the line in (b) d. Apply fault for 4 cycles, then trip the line in (b) and remove fault.
FLT_5_3PH	a. Apply 3-phase fault at the Holcomb bus (531449). b. Clear fault after 4 cycles by removing the line from Holcomb – Finney (531449 – 523853).
FLT_6_1PH	a. Apply 1-phase fault at the Holcomb bus (531449). b. Clear fault after 4 cycles by tripping one phase on the line from Holcomb – Finney 345kV (531449-523853). c. Wait 30 cycles, and then re-close the phase in (b) into the fault. d. Apply fault for 4 cycles, then trip the line in (b).
FLT_7_3PH	a. Apply 3-phase fault at the Potter bus (523961). b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700).
FLT_8_1PH	a. Apply 1-phase fault at the Potter bus (523961). b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700). c. Wait 30 cycles, and then re-close the line in (b) d. Apply fault for 4 cycles, then trip the line
FLT_9_3PH	a. Apply 3-phase fault at the GEN-2005-017 bus (51700). b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700).

FAULT	FAULT DESCRIPTION
FLT_10_1PH	a. Apply 1-phase fault at the GEN-2005-017 bus (51700). b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700). c. Wait 30 cycles, and then re-close the line in (b) d. Apply fault for 4 cycles, then trip the line
FLT_11_3PH	a. Apply 3-phase fault at the Grapevine bus (523771). b. Clear Fault after 5 cycles by removing line from Grapevine to Elk City (523771 – 511490). 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 (523771). b. Clear Fault after 5 cycles by removing line from Grapevine to Elk City (523771 – 511490). 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 (525481). b. Clear Fault after 5 cycles by removing line from Potter – Plant x (523959 – 525481). 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_14_1PH	a. Apply 1-phase fault at the Plant X bus (525481). b. Clear Fault after 5 cycles by removing line from Potter – Plant X (523959 – 525481). 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 (523344). b. Clear Fault after 5 cycles by removing line from Blackhawk – Pringle (523266 – 523344). 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 (523344). b. Clear Fault after 5 cycles by removing line from Blackhawk – Pringle (523266 – 523344). 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 (523959). b. Clear Fault after 5 cycles by removing line from Potter – Bushland 230kV (523959 – 524267). 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 (523959). b. Clear Fault after 5 cycles by removing line from Bushland – Potter 230kV (523959 – 524267). 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.

2.3 STUDY RESULTS

The results for the simulated disturbances are summarized in Table 2-4. The plots showing the simulation results are included in Appendix C. Based on the results of the previous GEN-2006-044 study, it was known that Fault 5 was the critical fault in this area. This fault was tested first, and then all faults were confirmed on the final solution.

The initial results for Fault 5 after adding GEN-2006-049 showed instability due to sustained, undamped oscillations of GEN-2006-044 and GEN-2006-049. This fault was tested on the pre-project cases and was found to be stable. As this fault is close to the GEN-2006-049 POI, the instability is thus attributed to the addition of the GEN-2006-049 wind plant. The following options are considered for improving the stability of the system.

<u>First Upgrade Option</u>:

The first upgrade options started with the addition of 345kV CKT#1 FROM MOORLAND TO NORTHWEST. This did not fix the instability of Fault 5, so CKT#2 was added FROM HITCHLAND TO MOORLAND and FROM MOORLAND TO NORTHWEST. Since the oscillations in the speeds of GEN-2006-044 and GEN-2006-049 persisted, an SVC addition was tested. The system became stable after addition of a 100 MVAR SVC at G02-08 (#66661) in addition to the line upgrades just discussed. Thus in option 1 the following transmission additions are considered sufficient to maintain stability:

1. *MOORLAND - NORTHWEST 345 KV CKT # 1*
2. *HITCHLAND - MOORLAND 345 KV CKT # 2*
3. *MOORLAND - NORTHWEST 345 KV CKT # 2*
4. *SVC - 100 MVA at bus #66661*

The case files are:

- Gen-2006-049_WP_line-3_SVC.SAV
- Gen-2006-049_SP_line-3_SVC.SAV

Figure 2-6 and Figure 2-7 show the PSS/E one-line diagrams after the addition of the above facilities for 2008 Winter Peak and 2012 Summer Peak respectively.

Fault-5 (FLT_5_3PH) was tested in dynamic simulation and found stable with this solution, with no wind farm tripping occurring. However, this solution is considered expensive so no further simulations were made with this option. A second option was tested as described in the following section.

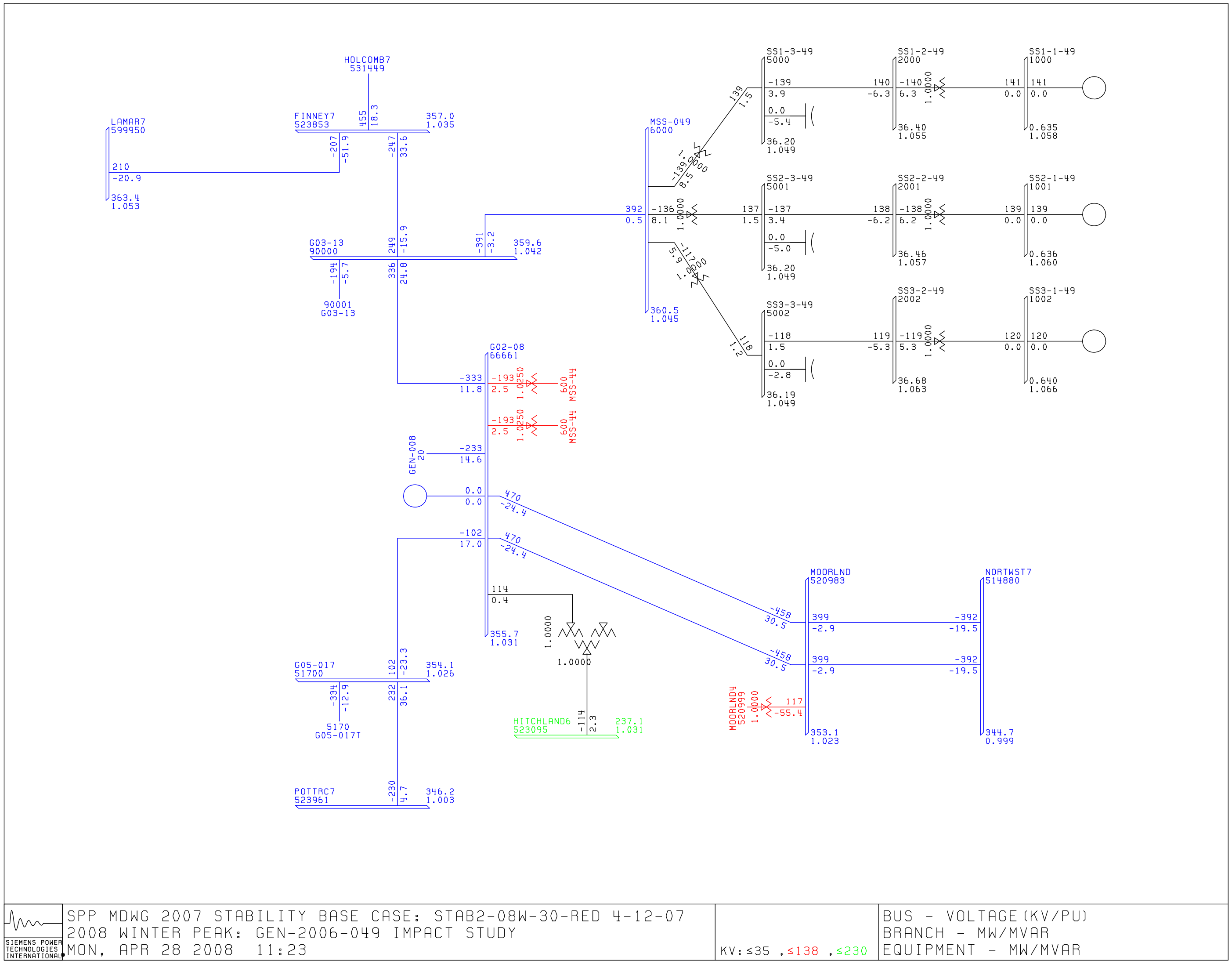

Figure 2-6 2008 Winter Peak Case with GEN-2006-049 (First Upgrade Option)

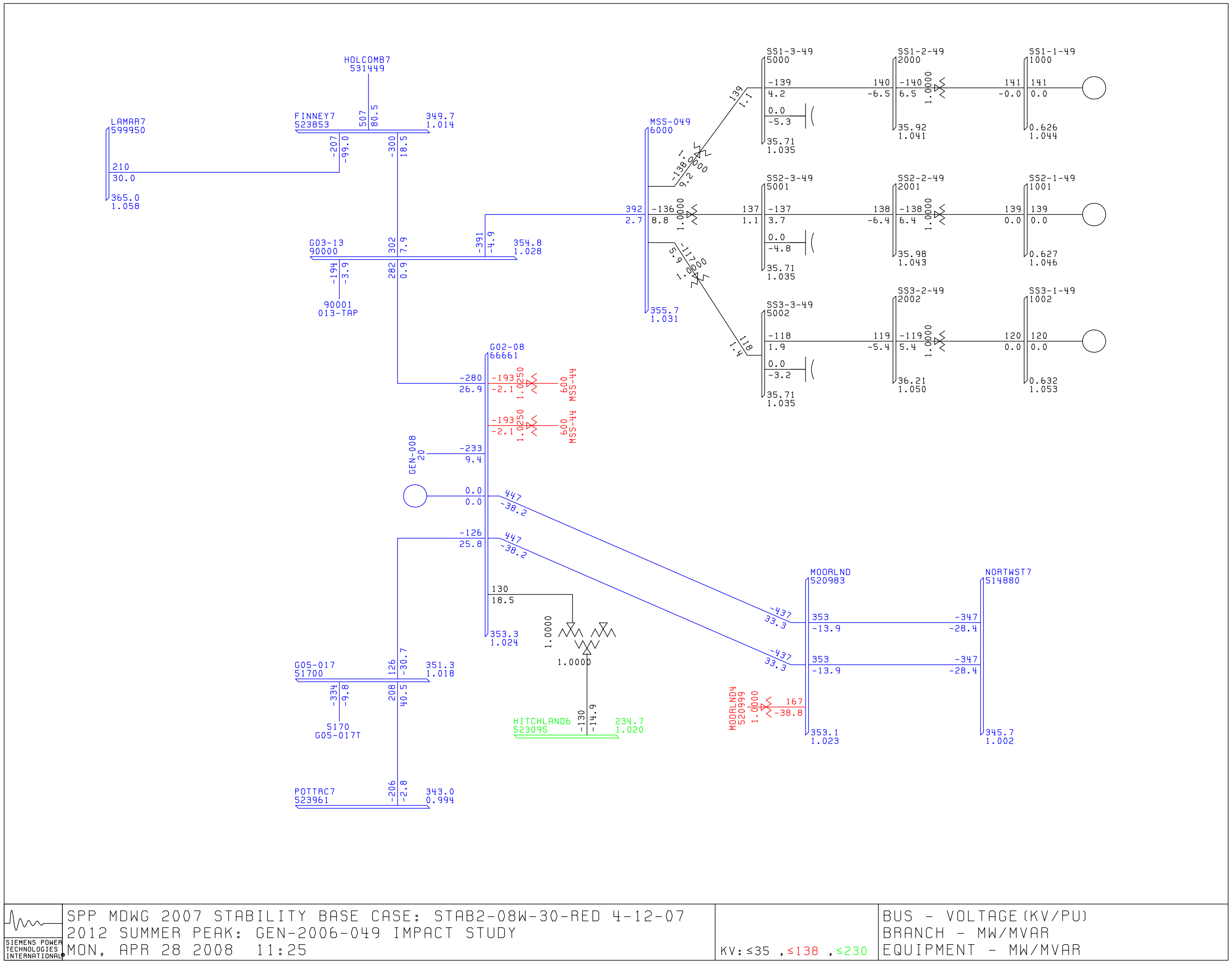

Figure 2-7 2012 Summer Peak Case with GEN-2006-049 (First Upgrade Option)

Second Upgrade Option

A second upgrade option was suggested by SPP which is the addition of 345 kV CKT #1 from GEN-2006-049 to Mooreland.

The post project cases are

- Gen-2006-049_WP_line-06-49.SAV
- Gen-2006-049_SP_line-06-49.SAV

The post-project power flow diagrams with the second upgrade option are given in Figure 2-8 and Figure 2-9.

With this option, the reactive power requirements to achieve unity power factor at the POI are 13.2, 12.7, and 9.5 Mvar at the three 34.5 kV substation buses, respectively, for a total of 35.4 Mvar.

All faults were simulated with the second upgrade option, and all were found to be stable for both 2008 winter peak and 2012 summer peak. The results for the Second Upgrade Option are summarized in Table 2-4.

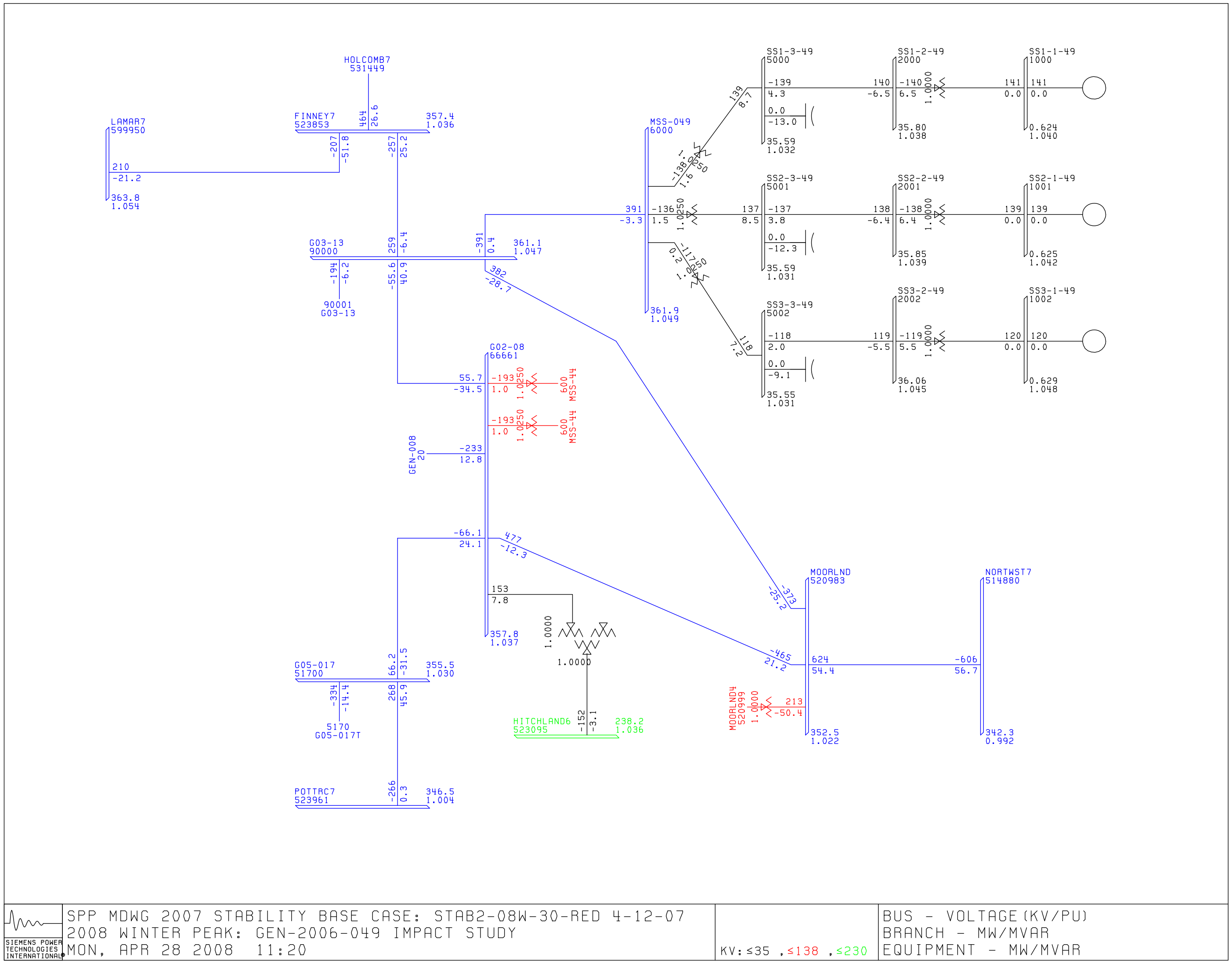

Figure 2-8 2008 Winter Peak Case with GEN-2006-049 (Second Upgrade Option)

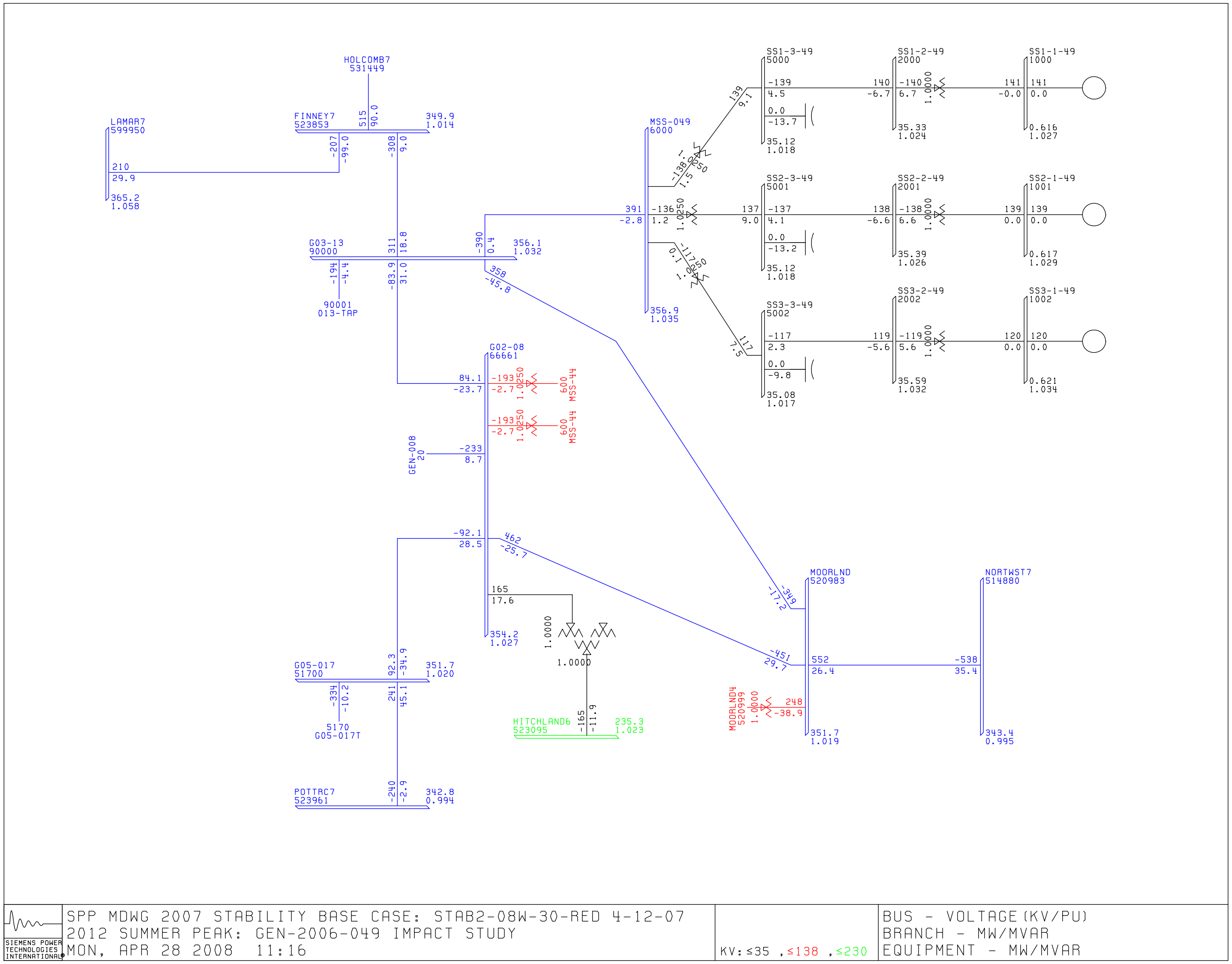

Figure 2-9 2012 Summer Peak Case with GEN-2006-049 (Second Upgrade Option)

Table 2-4 Results of Stability Simulations

	2008 Winter Peak				2012 Summer Peak			
FAULT	Pre-project	Post-project	First Upgrade Option – Post project	Second Upgrade Option – Post project	Pre-project	Post-project	First Upgrade Option – Post project	Second Upgrade Option – Post project
FLT_1_3PH	---	---	---	STABLE[2]	---	---	---	STABLE
FLT_2_1PH	---	---	---	STABLE	---	---	---	STABLE
FLT_3_3PH	---	---	---	STABLE[2]	---	---	---	STABLE
FLT_4_1PH	---	---	---	STABLE	---	---	---	STABLE
FLT_5_3PH	STABLE	UNSTABLE[1]	STABLE	STABLE	STABLE	UNSTABLE[1]	STABLE	STABLE
FLT_6_1PH	---	---	---	STABLE	---	---	---	STABLE
FLT_7_3PH	---	---	---	STABLE	---	---	---	STABLE
FLT_8_1PH	---	---	---	STABLE	---	---	---	STABLE
FLT_9_3PH	---	---	---	STABLE	---	---	---	STABLE
FLT_10_1PH	---	---	---	STABLE	---	---	---	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	---	---	---	STABLE
FLT_18_1PH	---	---	---	STABLE	---	---	---	STABLE

Notes:
1 GEN-2006-044 and GEN-2006-049 wind generators oscillate, not stable at the end of simulation
2 GEN-2003-013 initially tripped on undervoltage. Simulation was repeated with tripping disabled and all generators were stable.

3 CONCLUSIONS

The objective of this study was to evaluate the impact of the proposed GEN-2006-049 wind farm on the stability of SPP system. The study was performed for two system scenarios: the 2008 Winter Peak and the 2012 Summer Peak.

The system was unstable for a critical fault near the POI after interconnection of the proposed project. The same fault was stable in the pre-project cases. Two upgrade options were studied for GEN-2006-049 interconnection.

Option-1: Stable performance was found after the concurrent addition the following facilities:

5. *MOORLAND - NORTHWEST 345 KV LINE -1*
6. *MOORLAND - NORTHWEST 345 KV LINE -2*
7. *MOORLAND - HITCHLAND 345 KV LINE -2*
8. *SVC - 100 MVA at bus # 66661*

Option-2: Addition of 345KV CKT #1 FROM GEN-2006-049 TO MOORELAND. All tested faults were stable after this upgrade. Option 2 is the preferred upgrade due to its expected lower cost.

With Option 2, the reactive power requirements to achieve unity power factor at the POI are 13.2, 12.7, and 9.5 Mvar at the three 34.5 kV substation buses, respectively, for a total of 35.4 Mvar.

FERC Order 661A Compliance – With the new 345 kV line from GEN-2006-049 station to Mooreland, the GEN-2006-049 wind farm with Suzlon 2.1 MW turbines complies with the latest FERC order on low voltage ride through for wind farms. With this arrangement, the wind farm would not trip off line by voltage relay actuation for local faults near the POI.

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 - Plots for Stability Simulations