# Impact Study for Generation Interconnection Request GEN–2006–044 Restudy

*SPP Tariff Studies*
*(#GEN-2006-044 Restudy)*

**August 2008**

## Executive Summary

<OMITTED TEXT> (Customer) has requested a Impact Study for the purpose of interconnecting 400 MW of wind generation within the control area of Southwestern Public Service (SPS) primarily located in Texas County, Oklahoma and partially located in Hansford County, Texas. The proposed point of interconnection the 345kV substation proposed to be built for prior queued generation interconnection request GEN-2002-008 on the Potter – Finney 345kV transmission line owned by Southwestern Public Service (SPS). The proposed in-service date is October 1, 2010. This request is behind a prior queued request to interconnect into the same point. The prior queued request, GEN-2002-008, is for 240 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-2002-008. In addition, a new 345kV line to the Oklahoma Gas and Electric (OKGE) Woodward substation will be required for the interconnection of this wind farm. The wind farm was studied with General Electric 1.5sl wind turbines with +/-90% power factor capability. With these turbines, the Customer will not be required to install capacitors within their interconnection facilities.

A stability study was conducted for this generation interconnection request. 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 345kV line to Woodward.

The maximum amount of generation that can be accommodated without the addition of the 345kV line to Woodward is 170MW. A total of 370MW can be accommodated if the Finney – Holcomb 345kV line outage is mitigated by the addition of a $2^{nd}$ 345kV line from Finney – Holcomb. This assumes that the Hitchland 345/230kV upgrades are in service. The Hitchland 345/230kV upgrades are scheduled to be complete by 2011 and include the following facilities

- Hitchland 345/230kV autotransformer
- Hitchland 230/115kV autotransformer
- Hitchland – Pringle 230kV transmission line
- Hitchland – Moore County 230kV transmission line
- Hitchland – Perryton 230kV transmission line

The total minimum costs for interconnection are estimated at $120,000,000. These costs are listed in Table 2. The customer can interconnect 370MW for approximately $7,500,000.

The Impact Study has also determined that with the General Electric turbines provided with the LVRT II package (LVRTII) and the 345kV transmission line to Woodward in service, GEN-2006-044 will meet FERC Order #661A low voltage requirements for low voltage ride through. If the Hitchland-Woodward 345kV line is not in service, the wind farm will trip unless the LVRT II package is installed.

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.

**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 Hansford County, Texas to be interconnected into the proposed 345kV substation to be built for interconnection request GEN-2002-008. This substation is to be located along the Potter – 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-2002-008 substation will not be adequate for interconnecting the 400 MW of wind generation. Generator and voltage instability are encountered for certain contingencies that were studied in the analysis.

These results indicate that panhandle area of Texas cannot accommodate any more generation without sufficient outlets to the rest of the SPP transmission system. Therefore, the interconnection of GEN-2006-044 will require the addition of a 345kV transmission line to the east. For this study, a 345kV transmission line from GEN-2002-008 (Hitchland) to the Oklahoma Gas and Electric (OKGE) Woodward substation was analyzed. The analysis has indicated that stability issues will be alleviated with the addition of this 345kV transmission line. Therefore, GEN-2006-044 interconnection Customer is responsible for the addition of this transmission line.

The proposed Hitchland-Woodward 345kV transmission line is not a definitive project at this time. The approximate distance from Hitchland to Woodward is estimated at 120 miles. With necessary substation construction, the line and substation work is estimated to cost approximately $120,000,000. This estimate will be refined during the course of a Facility Study if the Customer wishes to execute the Facility Study Agreement.

The facilities necessary to interconnect at 370MW include a new second circuit from Holcomb – Finney, an SPS – Sunflower tie line. This work is shown in Table 3. and will cost approximately $7,500,000.

The Impact Study has also determined that with the General Electric turbines provided with the LVRT II package (LVRTII) and the 345kV transmission line to Woodward in service, GEN-2006-044 will meet FERC Order #661A low voltage requirements for low voltage ride through. If the Hitchland-Woodward 345kV line is not in service, the wind farm will trip unless the LVRT II package is installed.

**Table 1. Interconnection Facilities**

| FACILITY | ESTIMATED COST (2007 DOLLARS) |
|---|---|
| CUSTOMER – (3) 115/34.5 kV collector substation facilities. | * |
| CUSTOMER – (3) 115 kV transmission facilities between the three Customer 115/34.5 kV collector substation facilities and the Customer 345/115 kV switching station. | * |
| CUSTOMER – (2) 345/115 kV transformers and all related 345/115 kV switching equipment located at the Customer 345/115 kV switching station. | * |
| CUSTOMER – (1) 345 kV tie between Customer 345/115 kV switching station and the point of interconnection. | * |
| CUSTOMER – Right-of-Way for Customer facilities. | * |
| | |
| **TOTAL** | * |

* Determined by Customer

**Table 2. Network Upgrades for 400MW**

| FACILITY | ESTIMATED COST (2008 DOLLARS) |
|---|---|
| Various Transmission Owners - Add (2) 345 kV terminals to Hitchland substation; build 120 miles of 345kV line to OKGE Woodward substation, and build 345kV switchyard and autotransformer at the Oklahoma terminal point. | $120,000,000 |
| | |
| **TOTAL** | **$120,000,000** |

**Table 3. Network Upgrades for 370MW**

| FACILITY | ESTIMATED COST (2008 DOLLARS) |
|---|---|
| SPS – Add terminal at Hitchland (needed for 170MW) | $1,000,000 |
| SPS – Add second circuit from Finney – Holcomb | $1,954,654 |
| SPS – Substation work at Finney | $1,548,324 |
| SUNC – Substation work at Holcomb | $2,970,000 |
| | |
| **TOTAL** | **$7,472,978** |

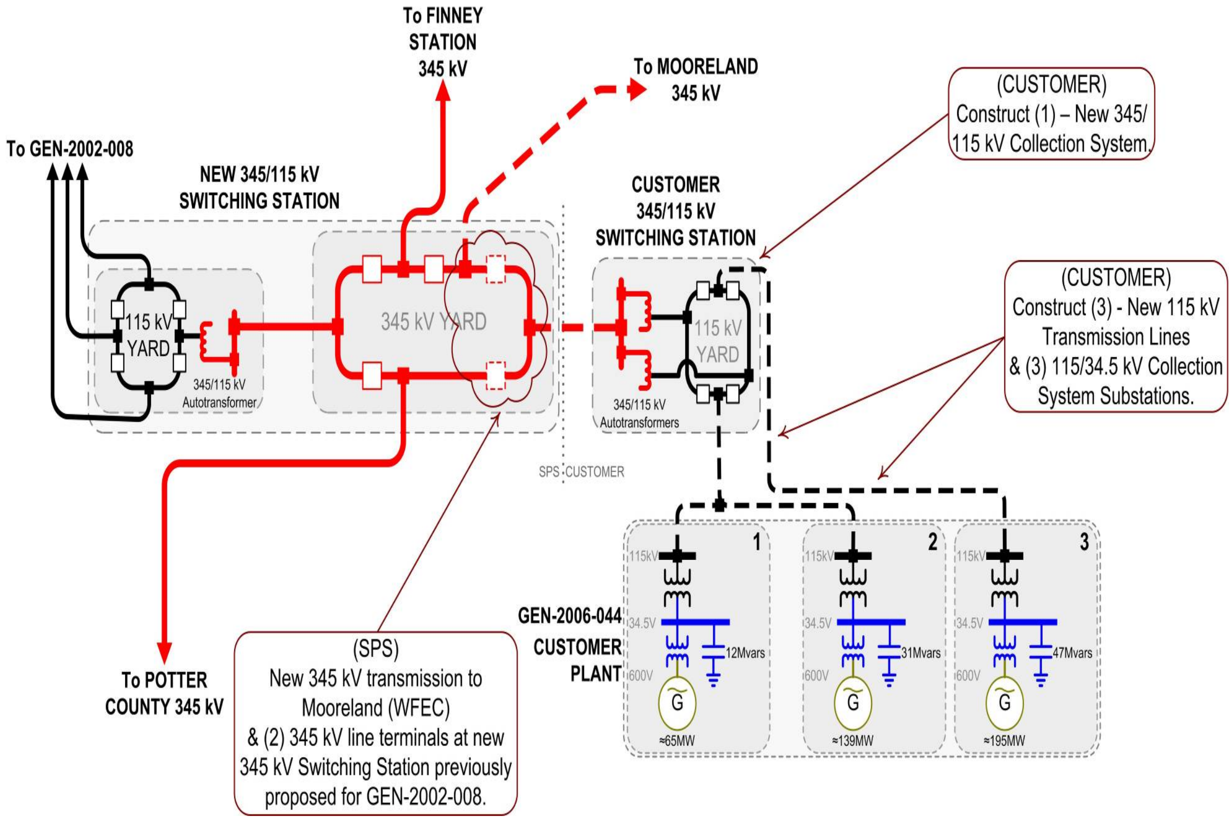


**Figure 1. Proposed Interconnection Configuration**
**(Final designs to be determined)**

POWER SYSTEMS DIVISION
GRID SYSTEMS CONSULTING

# IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2006-044 RESTUDY

# FINAL REPORT

REPORT NO.: 2008-11790-R0
Issued: August 15, 2008

**ABB Inc.**
**Power Systems Division**
**Grid Systems Consulting**
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# Legal Notice

# ABB Inc – Grid Systems Consulting

**Technical Report**

| **Southwest Power Pool** | **No.** 2008-11790-R0 | |
|---|---|---|
| Impact Study for Generation Interconnection request GEN-2006-044 Restudy | 8/15/2008 | # Pages 49 |


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**Reviewed by:** Bill Quaintance

**Approved by:** 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 Hansford County, Texas. This wind farm will be interconnected into a proposed 345 kV switching station on the Potter – Finney 345 kV line. The proposed station is to be built for generation interconnection request GEN-2002-008. 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 GE 1.5 MW wind turbines. Maximum plant size with no upgrades was also determined. Faults were simulated on the SPP system for Winter Peak 2008 and Summer Peak 2012 conditions.

The system was unstable with 400 MW following numerous 345 kV faults at or near the POI after interconnection of the proposed project. The same faults are stable before interconnecting GEN-2006-044. To achieve stable system operation, the simulations were repeated with reduced MW at GEN-2006-044. With 170 MW, both seasons (2008 winter peak and 2012 summer peak) were stable. However, the GE 1.5 MW wind generators trip on under-voltage. The system and GEN-2006-044 plant remain stable if voltage tripping is disabled (or a better LVRT package is purchased). The limiting fault is on the Holcomb-Finney 345 kV line.

If this critical outage is mitigated, for example by adding a second circuit, then GEN-2006-044 can increase to 370 MW, limited by the Finney to G03-13 345 kV line fault.

To dispatch the full 400 MW of generation, adding a new 345 kV line from the GEN-2002-008 station to Mooreland was studied. The system was stable with this upgrade for all studied faults. This new 345 kV line to Mooreland, including a 345/138 kV transformer at Mooreland, was shown to be an acceptable solution. With this solution, stability is maintained and wind farms remain on line following all tested faults.


| Rev No. | Revision Description | Date | Authored by | Reviewed by | Approved by |
|---|---|---|---|---|---|
| 0 | Draft Report | 8/15/2008 | Sunil Verma | Bill Quaintance | Willie Wong |
| DISTRIBUTION: Charles Hendrix – Southwest Power Pool | | | | | |

**FERC Order 661A Compliance** – With the new 345 kV line from GEN-2002-008 station to Mooreland, the GEN-2006-044 wind farm with GE 1.5 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 Hansford County, Texas. This wind farm will be interconnected into a proposed 345 kV switching station on the Potter – Finney 345 kV line. The proposed station is to be built for generation interconnection request GEN-2002-008. This transmission line is owned Southwestern Public Service (d/b/a Xcel Energy). GEN-2006-044 was previously studied assuming Suzlon S88 wind turbines. In this study, the GEN-2006-044 wind farm uses GE 1.5 MW wind turbines. 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 proposed 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.

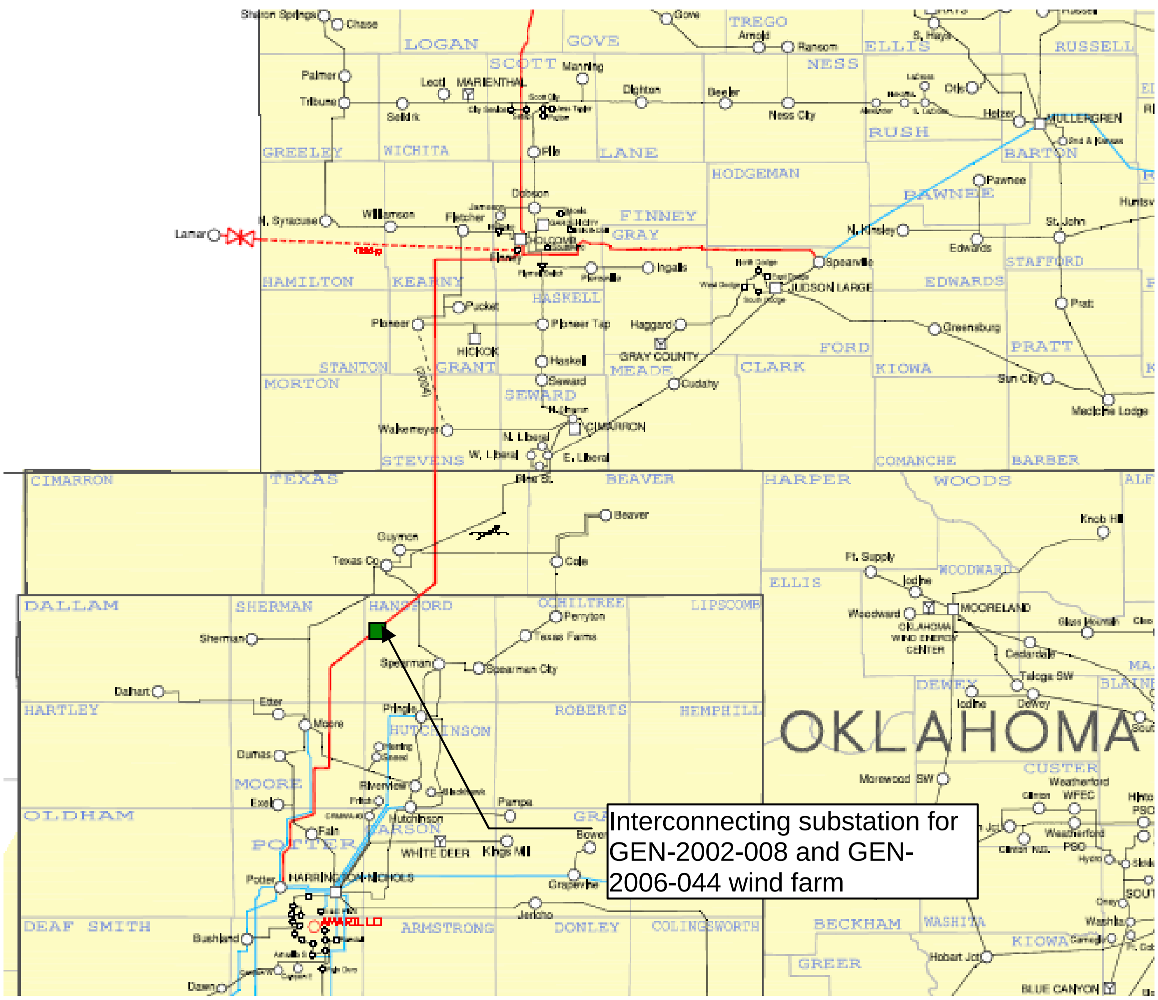


**Figure 1-1 Wind farm GEN-2002-008 and GEN-2006-044 interconnecting substation**

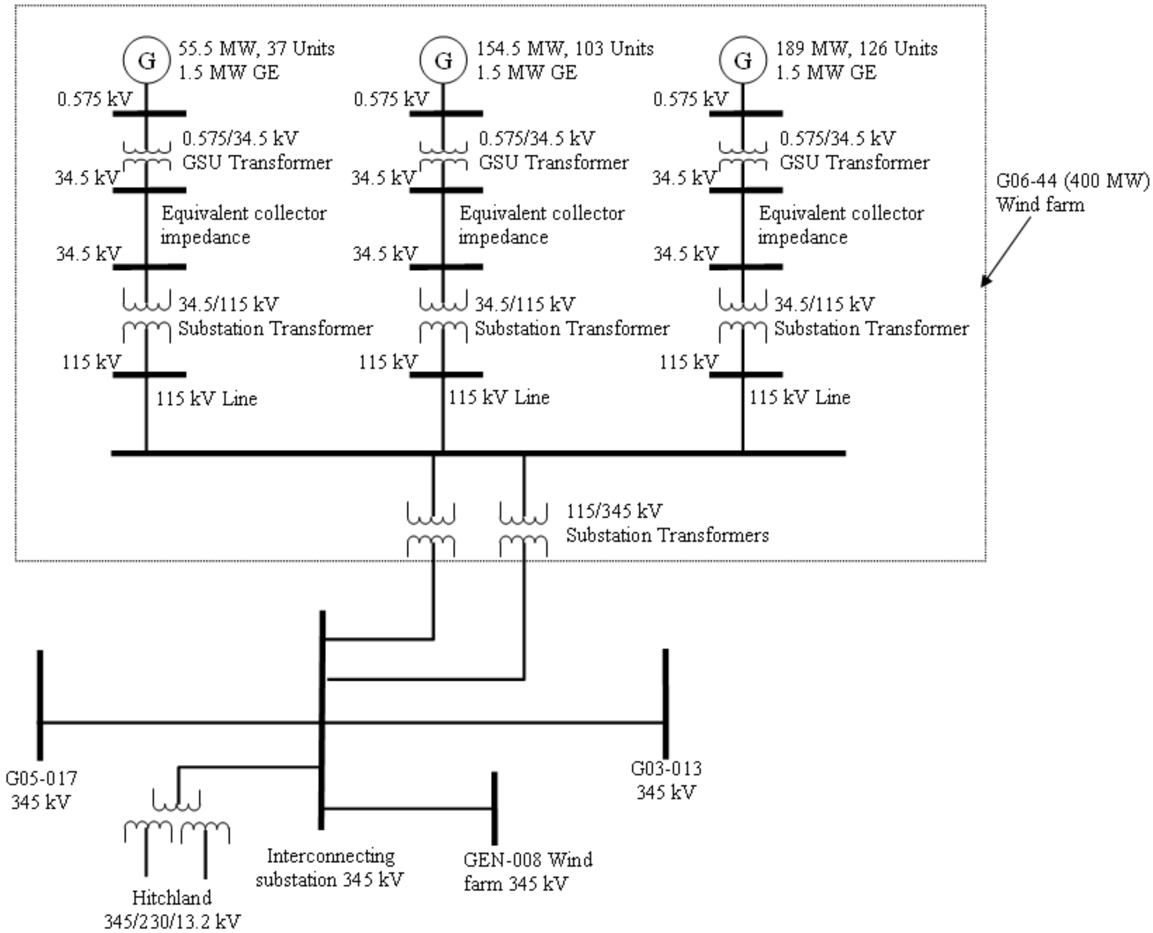


**Figure 1-2 Proposed 400 MW wind farm interconnection**

# 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 Cases***

This study used the power flow cases from the previous GEN-2006-044 impact study – "*gen-2006-044_08WP_upg2.sav*" representing the 2008 Winter Peak conditions and "*gen-2006-044_12sp_upg2.sav*" representing the 2012 Summer Peak conditions. These cases included GEN-2006-044 using Suzlon S88 turbines. These cases also include the planned Hitchland 345/230/115 kV tie station.

The cases are first converted to Pre-project cases by deleting the old GEN-2006-044 wind farm. These cases are named:

- *gen-2006-044_08WP_upg2-PRE.sav* – a 2008 winter peak case
- *gen-2006-044_12sp_upg2-PRE.sav* – a 2012 summer peak case

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

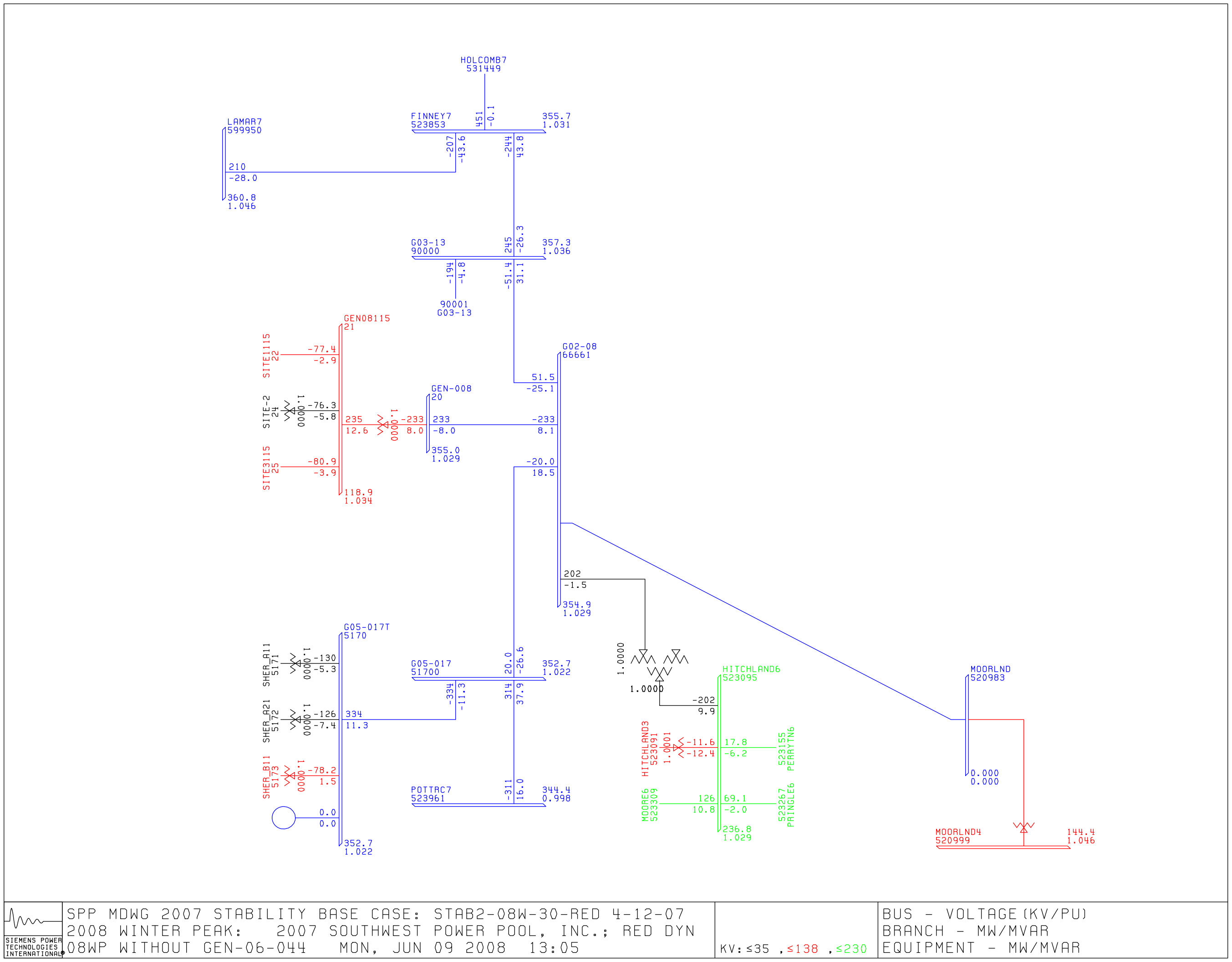


**Figure 2-1 Final 2008 Winter Peak Case without GEN-2006-044**

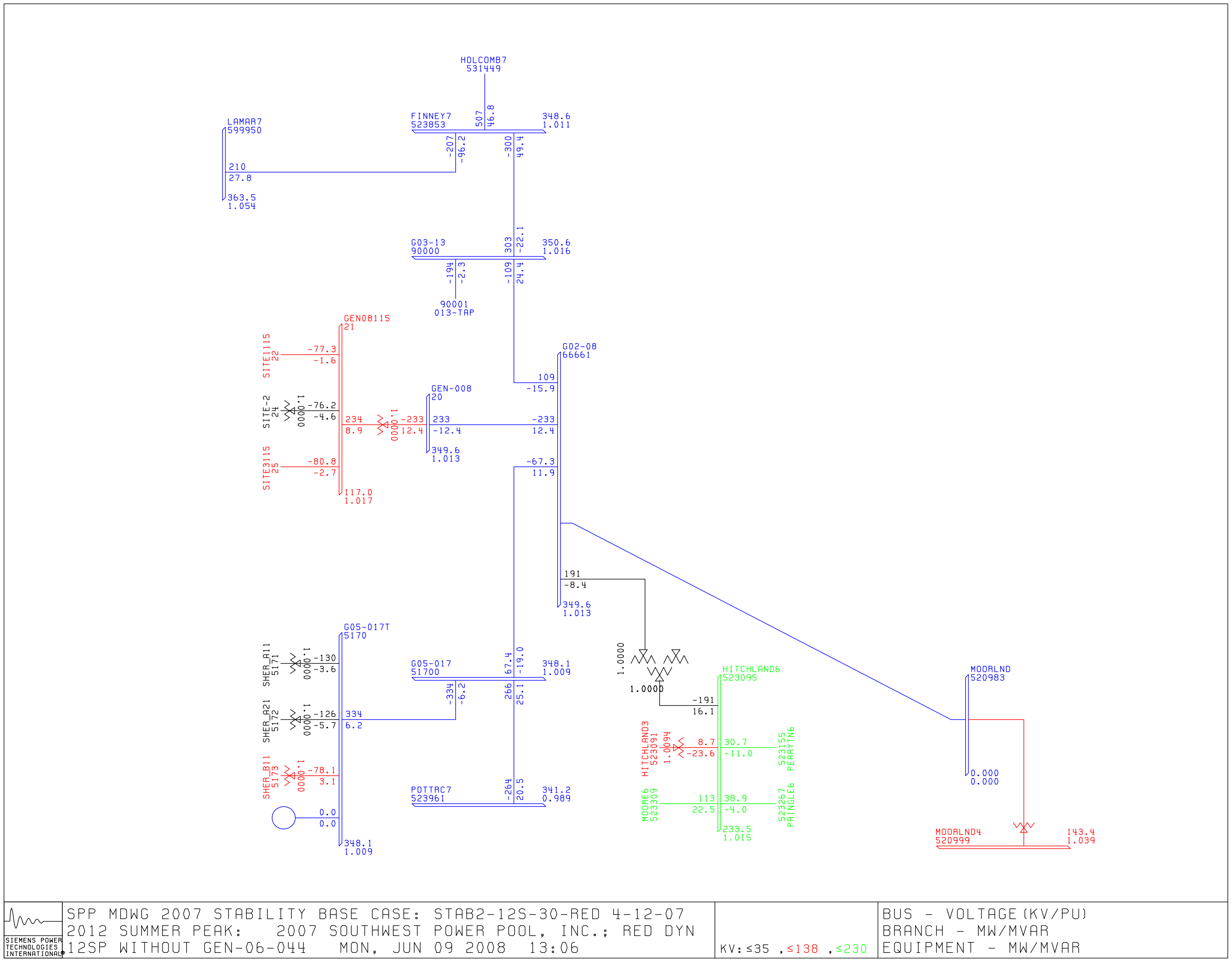


**Figure 2-2 Final 2012 Summer Peak Case without GEN-2006-044**

***GEN-2006-044 Wind Farm Power Flow Model***

The GEN-2006-044 wind farm will consist of 266 GE 1.5 MW wind turbine generators that will be split among three different collector substations. The 266 turbines are modeled as three equivalents as follows:

- Equivalent-1: equivalent of 37 GE 1.5 MW wind turbine generators connected at SS-1 substation
- Equivalent-2: equivalent of 103 GE 1.5 MW wind turbine generators connected at SS-2 substation
- Equivalent-3: equivalent of 126 GE 1.5 MW wind turbine generators connected at SS-3 substation

See Figure 2-3. Each equivalent generator is connected to an equivalent 34.5 kV collector branch through an equivalent 0.575/34.5 kV generator step-up transformer. Each of the three 34.5/115 kV substation transformers is explicitly modeled.

The three substations are connected to the POI via three 115 kV lines and two parallel 115/345 kV transformers. The detailed process of wind farm model development is described in Appendix A.

The voltage schedules of the generators were adjusted to achieve approximately unity power factor at the POI (i.e. zero reactive power exchange with the grid).

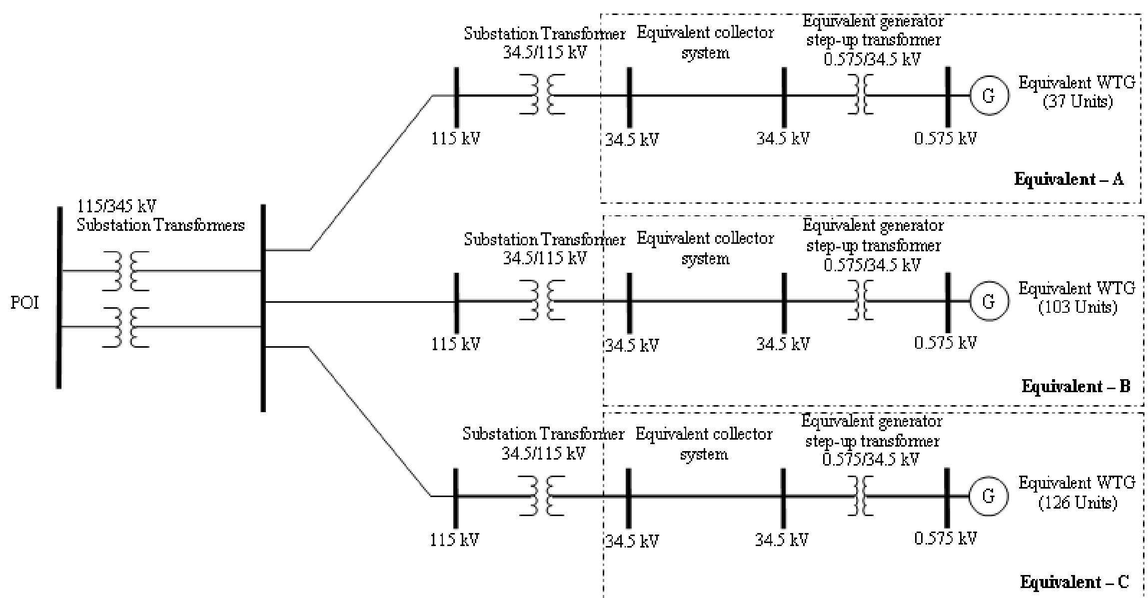


**Figure 2-3 GEN-2006-044 Model One-line Diagram**

***Post-Project Dispatch***

The GEN-2006-044 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 same location as the GEN-2002-008 wind plant, bus 66661. 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 summarized in Table 2-1. Thus two power flow cases with GEN-2006-044 were established:

- gen-2006-044_08WP_upg2-POST.sav – a 2008 winter peak case
- gen-2006-044_12sp_upg2-POST.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-2006-044 project details

| System condition | MW | Location | Point of Interconnection | Sink |
|---|---|---|---|---|
| Winter Peak | 400 | Hansford County, Texas | Substation at Potter – Finney 345kV line (#66661) | Areas 502, 524, 525, 536, 540, 541, 544 |
| Summer Peak | 400 | Hansford County, Texas | Substation at Potter – Finney 345kV line (#66661) | Areas 502, 524, 525, 536, 540, 541, 544 |

***Stability Database***

SPP provided the stability database in the form of PSS/E dynamic data files, "*gen-2006-044_08wp.dyr*" to model the 2008 Winter Peak configuration, and "*gen-2006-044_12sp.dyr*" to model the 2012 Summer Peak configuration. Command files were also provided to compile and link user-written models. These files are compatible with PSS/E version 30.2.1.

The stability data for GEN-2006-044 was appended to the Pre-project data. The dynamic model for the GE 1.5 MW wind turbines was generated using PSS/E Wind program "gewinda.IRF". This program generates stability data using collector system information and GE 1.5 MW machine data "ge15f60a.dat". 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: GE 1.5 MW Voltage Trip Settings

| V (pu) | time (s) |
|---|---|
| 1.30 | 0.02 |
| 1.15 | 0.10 |
| 1.10 | 1.00 |
| 0.85 | 10.00 |
| 0.75 | 1.00 |
| 0.70 | 0.10 |
| 0.30 | 0.02 |

The PSS/E power flow and stability model data for GEN-2006-044 are included in Appendix B.

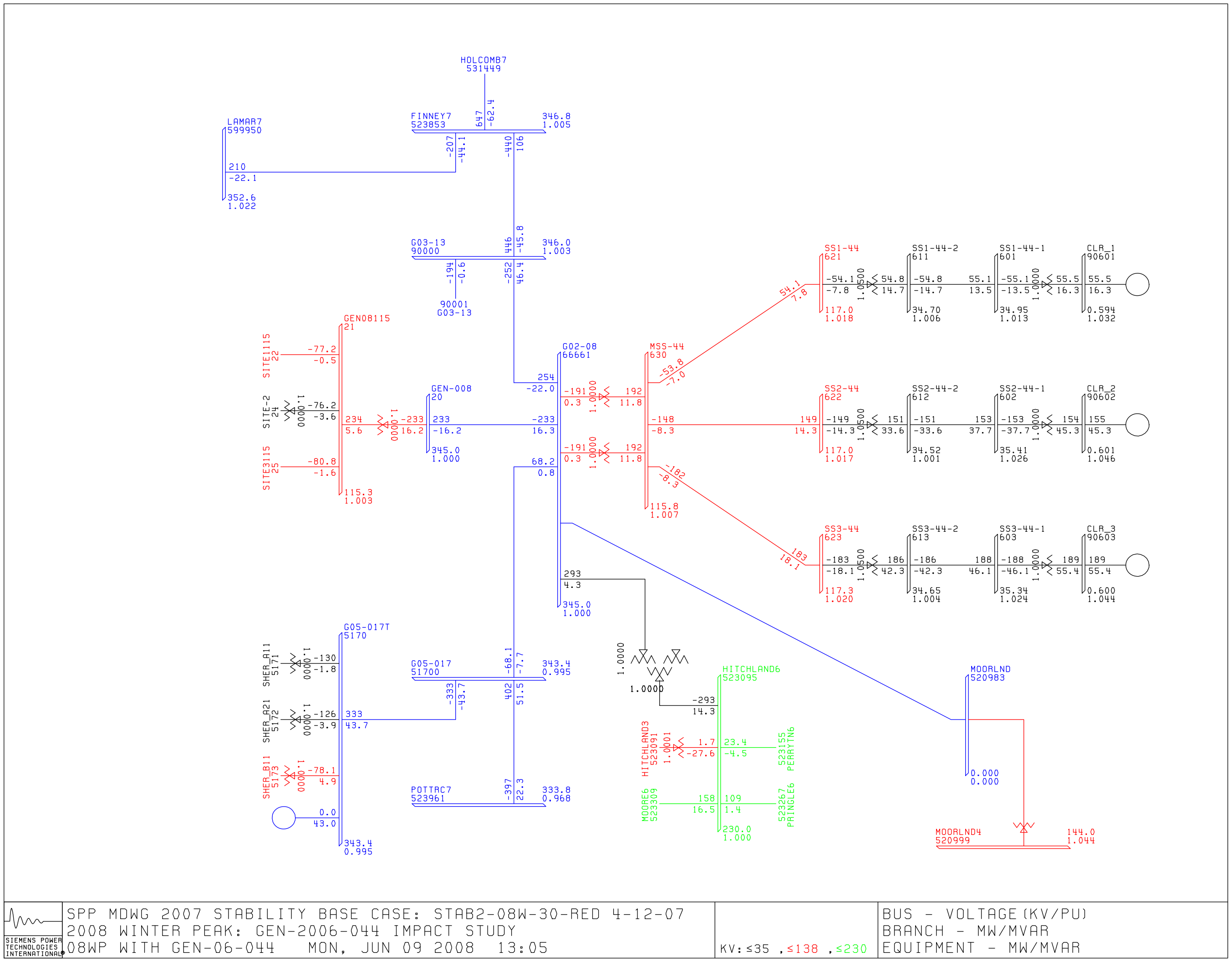


**Figure 2-4 2008 Winter Peak Case with GEN-2006-044**

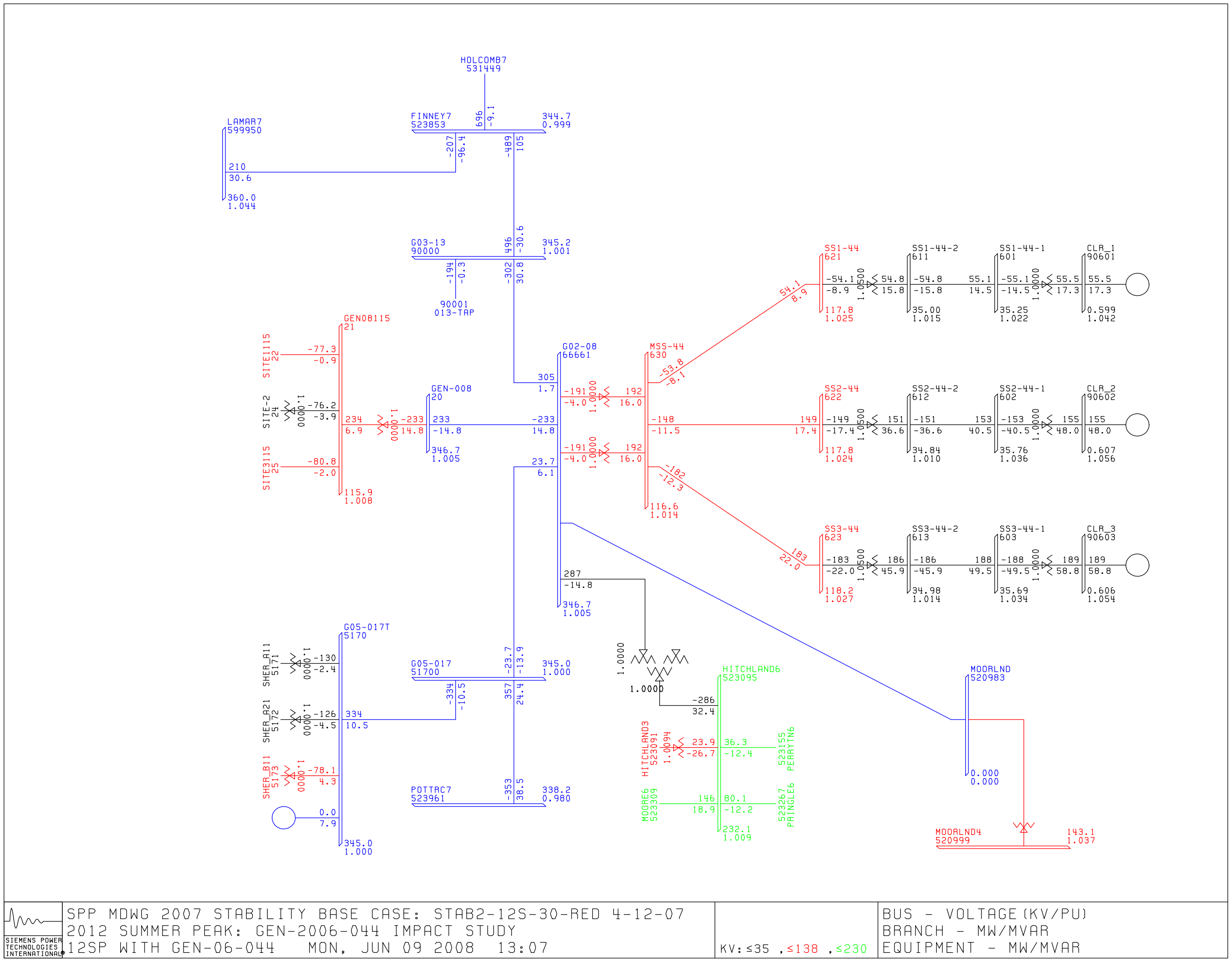


**Figure 2-5 2012 Summer Peak Case with GEN-2006-044**

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

**Table 2-3 List of Faults for Stability Analysis**

| *Fault Name* | *Description* |
|---|---|
| FLT_1_3PH | a. Apply 3-phase fault at the GEN-2006-044 bus (66661).<br>b. Clear fault after 4 cycles by removing the line from GEN-2006-044 to GEN-2003-013 345kV (66661 to 90000). |
| FLT_2_1PH | a. Apply 1-phase fault at the GEN-2006-044 bus (66661).<br>b. Clear fault after 4 cycles by tripping the line from GEN-2002-008 to GEN-2003-013 345kV (66661 to 90000).<br>c. Wait 30 cycles, and then re-close the phase in (b) into the fault.<br>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-2002-008 bus (66661).<br>b. Clear fault after 4 cycles by removing the line from GEN-2002-008 to GEN-2005-017 345kV (66661 – 51700). |
| FLT_4_1PH | a. Apply 1-phase fault at the GEN-2002-008 bus (66661).<br>b. Clear fault after 4 cycles by tripping the line from GEN-2002-008 – GEN-2005-017 345kV (66661 to 51700).<br>c. Wait 20 cycles, and then re-close the line in (b)<br>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).<br>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).<br>b. Clear fault after 4 cycles by tripping one phase on the line from Holcomb – Finney 345kV (531449-523853).<br>c. Wait 30 cycles, and then re-close the phase in (b) into the fault.<br>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).<br>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).<br>b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700).<br>c. Wait 30 cycles, and then re-close the line in (b)<br>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).<br>b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700). |

| Fault Name | Description |
|---|---|
| FLT_10_1PH | a. Apply 1-phase fault at the GEN-2005-017 bus (51700).<br>b. Clear fault after 4 cycles by removing the line from Potter – GEN-2005-017 (523961 – 51700).<br>c. Wait 30 cycles, and then re-close the line in (b)<br>d. Apply fault for 4 cycles, then trip the line |
| FLT_11_3PH | a. Apply 3-phase fault at the Grapevine bus (523771).<br>b. Clear Fault after 5 cycles by removing line from Grapevine to Elk City (523771 – 511490).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Grapevine to Elk City (523771 – 511490).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Potter – Plant x (523959 – 525481).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Potter – Plant X (523959 – 525481).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Blackhawk – Pringle (523266 – 523344).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Blackhawk – Pringle (523266 – 523344).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Potter – Bushland 230kV (523959 – 524267).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>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).<br>b. Clear Fault after 5 cycles by removing line from Bushland – Potter 230kV (523959 – 524267).<br>c. Wait 20 cycles, and then re-close line in (b) into the fault.<br>d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault. |

| ***Fault Name*** | ***Description*** |
|---|---|
| FLT_19_3PH | a. Apply 3-phase fault at the GEN-2002-008 345 kV bus (66661).<br>b. Clear fault after 4 cycles by removing the 345 kV line from GEN-2002-008 to Mooreland. |
| FLT_20_3PH | c. Apply 3-phase fault at the GEN-2002-008 345 kV bus (66661).<br>d. Clear fault after 4 cycles by removing the 3 winding transformer (345/230/13.2 kV). |
| FLT_21_3PH | a. Apply 3-phase fault at the FINNEY7 345 kV bus (523853).<br>b. Clear fault after 4 cycles by removing the 345 kV line from FINNEY7 (523853) to G03-13 (90000). |

## 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.

The initial results of the critical Fault 5 showed instability in the post-project cases. This fault involves the loss of the Holcomb-Finney 345 kV line. This fault was repeated in the pre-project cases, and it was stable in the pre-project scenario. As this fault is close to the GEN-2006-044 POI, the instability is thus attributed to the addition of the GEN-2006-044 wind plant.

***Maximum MW with no upgrades***

To achieve the stable operation, the MW from GEN-2006-044 was reduced in steps of 10 MW. The system achieves angular stability at 180 MW for both cases (2008 winter peak and 2012 summer peak). However, with GEN-2006-044 at 180 MW in the 2008 winter peak case, the real and reactive power are oscillating at other wind generators connected at buses 90100 and 90103. These oscillations are eliminated by reducing the GEN-2006-044 plant size to 170 MW.

The comparison of 180 MW and 170 MW cases are shown in Figure 2-6.

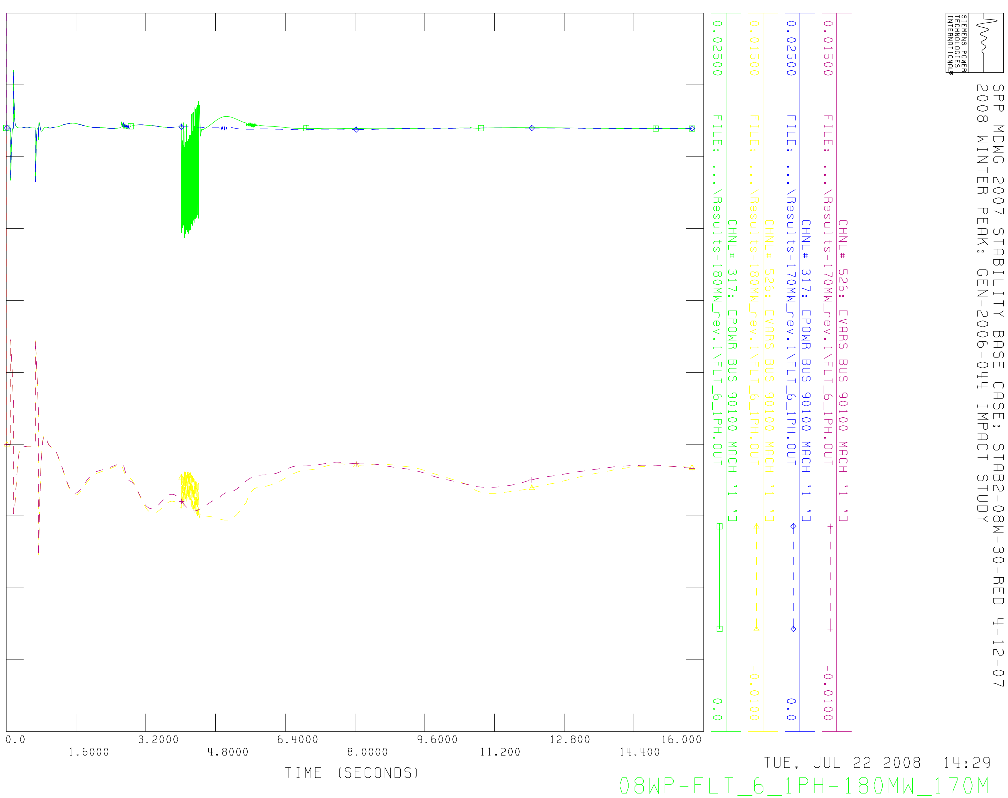


**Figure 2-6 Comparison of oscillations for 180 MW & 170 MW for 2008 winter peak case on FLT_6_1PH**

Figure 2-8 and Figure 2-9 show the PSS/E one-line diagrams with the reduced GEN-2006-044 generation (170 MW) for 2008 Winter Peak and 2012 Summer Peak respectively.

Note however that at 170 MW, the GEN-2006-044 generators trip for faults 1, 3 and 20 on undervoltage condition. These are 4 cycle faults at the POI, which leads to voltage reaching beyond 0.3 pu for more than 0.02 sec. If undervoltage tripping is disabled, the system remains stable. The results are summarized in Table 2-4.

***<u>Fault at Finney to G03-13 345 kV Line</u>***

The Holcomb-Finney 345 kV line of Fault 5 may be fixed in the near future, possibly with a new second circuit. The next most severe fault is Fault 21 on the Finney to G03-13 345 kV line. This fault leads to Power and VAR oscillations in wind farms connected at bus #90100 and #90103 for **2008 winter** peak case. These oscillations are not observed in **2012 summer** peak case even with full generation (400 MW) of GEN-2006-044.

Reducing generation to 370 MW at GEN-2006-044 eliminates these oscillations in the 2008 winter peak case. A comparison of oscillations observed in the 2008 winter peak case for 380 MW and 370 MW generations from GEN-2006-044 is shown in Figure 2-7.

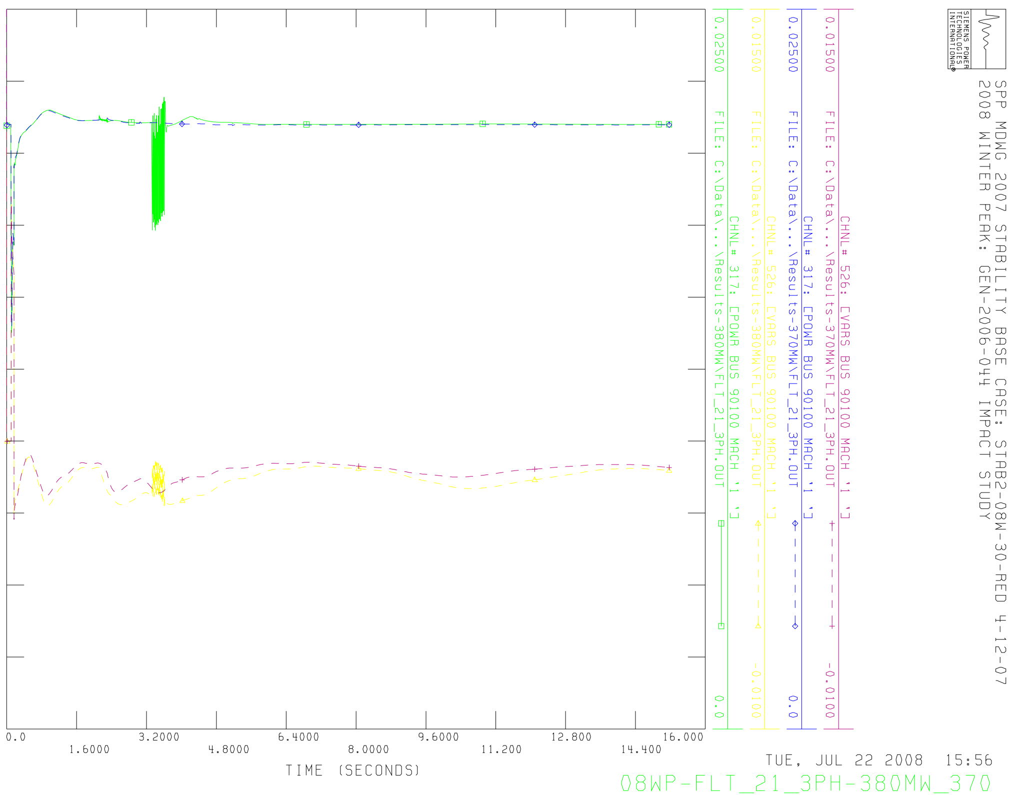


**Figure 2-7 Comparison of oscillations for 380 MW & 370 MW for 2008 winter peak case on FLT_21_3PH**

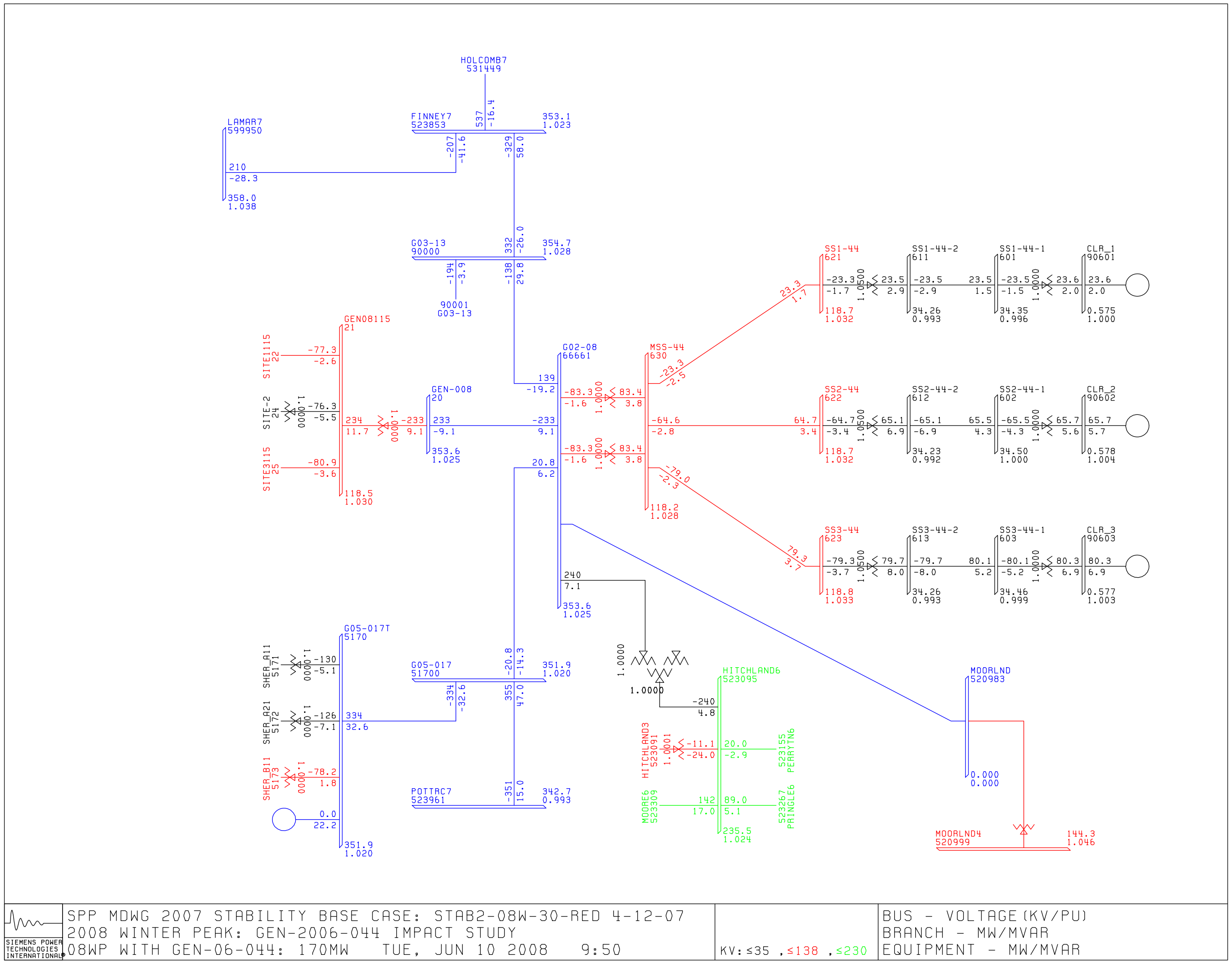


**Figure 2-8 2008 Winter Peak Case with reduced GEN-2006-044 (170 MW)**

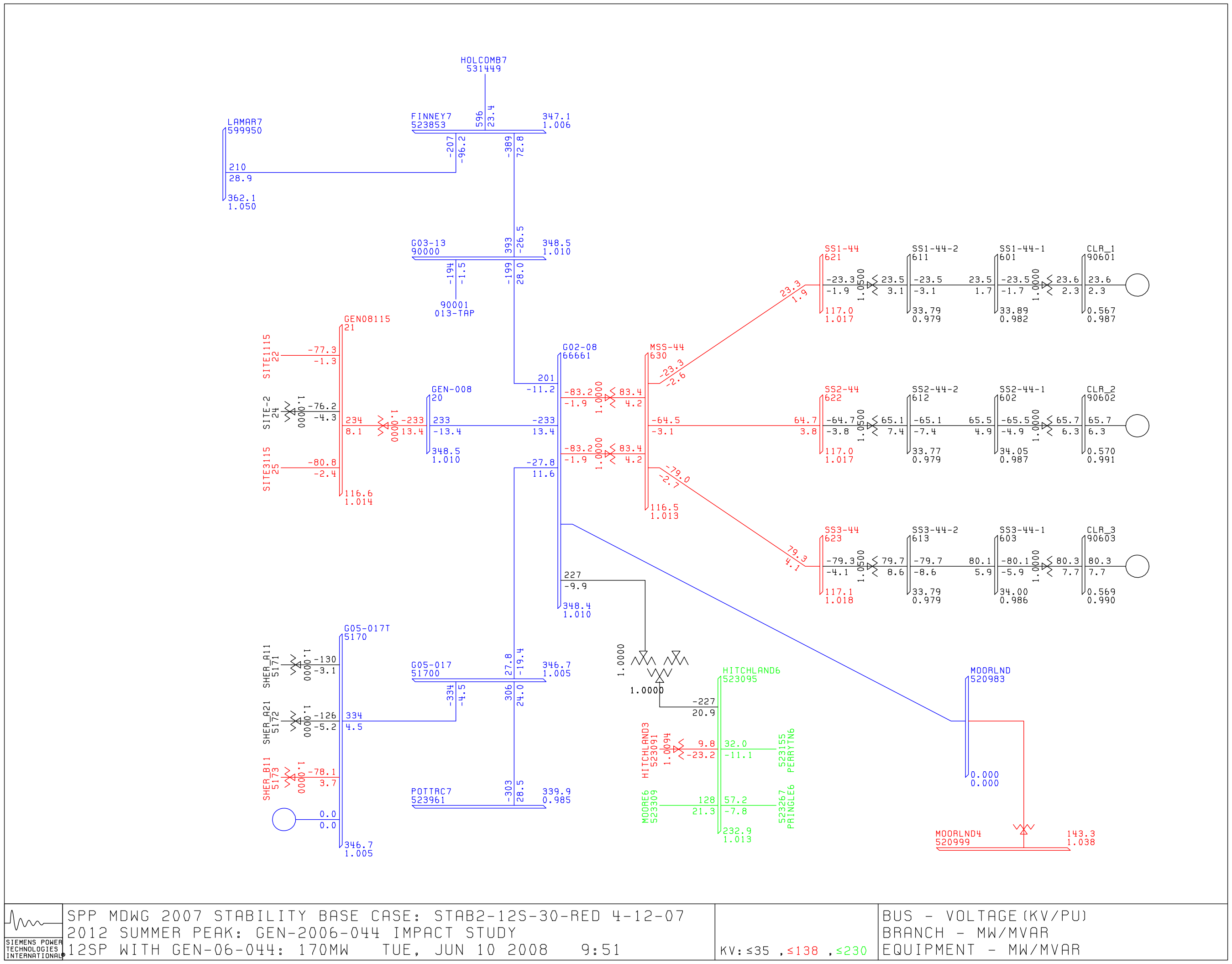


**Figure 2-9 2012 Summer Peak Case with reduced GEN-2006-044 (170 MW)**

***New 345 kV Line from GEN-2002-008 Station to Mooreland***

The addition of a new 345 kV line from the POI (GEN-2002-008 Station) to Mooreland was tested in dynamic simulations. This solution includes a 345/138 kV transformer connecting the new 345 kV line to the existing Mooreland 138 kV switchyard. Figure 2-10 and Figure 2-11 show the PSS/E one-line diagrams after the addition of the new 345 kV line for 2008 Winter Peak and 2012 Summer Peak respectively.

All Faults are stable with this solution, with no wind farm tripping occurring, as summarized in Table 2-4. Adding this transmission line will allow GEN-2006-044 to operate at its full proposed size of 400 MW.

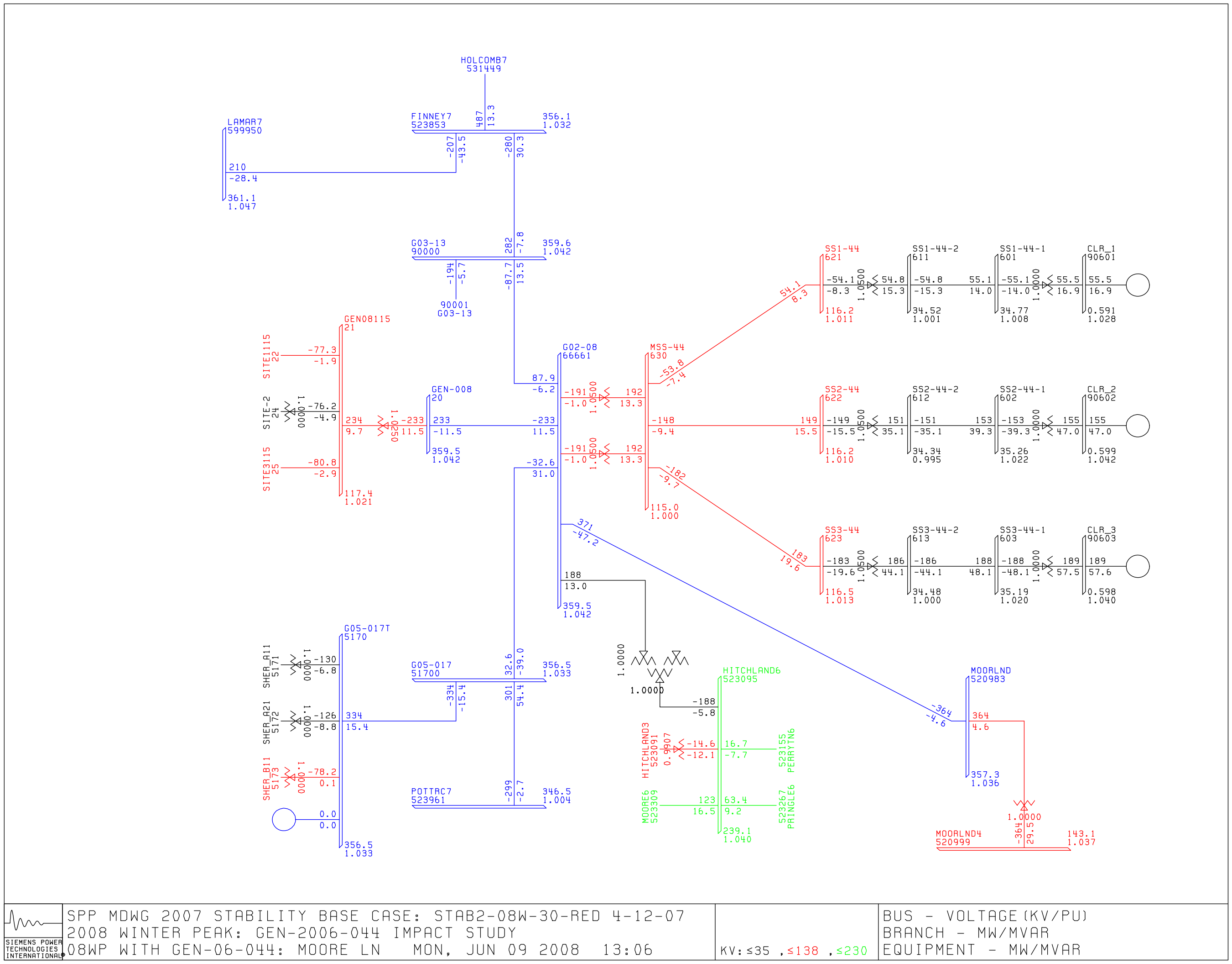


**Figure 2-10 2008 Winter Peak Case with GEN-2006-044 with New Line (GEN-2002-008 – Mooreland)**

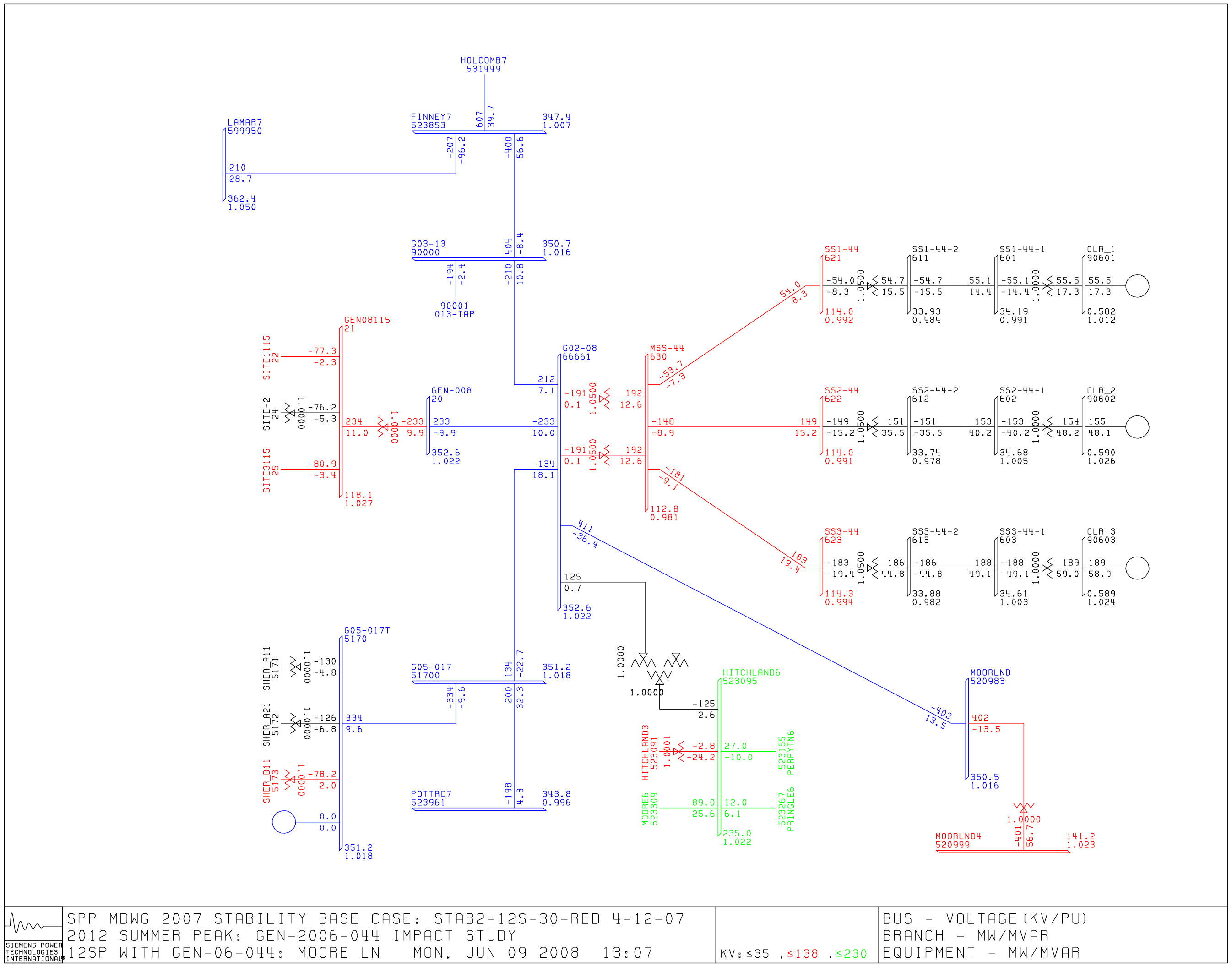


**Figure 2-11 2012 Summer Peak Case with GEN-2006-044 with New Line (GEN-2002-008 – Mooreland)**

**Table 2-4 Results of Stability Simulations**

| | 2008 Winter Peak | | | | 2012 Summer Peak | | | |
|---|---|---|---|---|---|---|---|---|
| **FAULT** | **Pre-project** | **Post-project** | **Post-project with reduced generation (170 MW)** | **Post-project with Line (GEN-2002-008 station to Mooreland)** | **Pre-project** | **Post-project** | **Post-project with reduced generation (170 MW)** | **Post-project with Line (GEN-2002-008 station to Mooreland)** |
| FLT_1_3PH | STABLE | --- | STABLE* | STABLE | STABLE | --- | STABLE* | STABLE |
| FLT_2_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_3_3PH | STABLE | --- | STABLE* | STABLE | STABLE | --- | STABLE* | STABLE |
| FLT_4_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_5_3PH | STABLE | UNSTABLE | STABLE | STABLE | STABLE | UNSTABLE | STABLE | STABLE |
| FLT_6_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_7_3PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_8_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_9_3PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_10_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_11_3PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_12_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_13_3PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_14_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_15_3PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_16_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_17_3PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_18_1PH | --- | --- | STABLE | STABLE | --- | --- | STABLE | STABLE |
| FLT_19_3PH | --- | --- | --- | STABLE | --- | --- | --- | STABLE |
| FLT_20_3PH | STABLE | --- | STABLE* | STABLE | STABLE | --- | STABLE* | STABLE |
| FLT_21_3PH | --- | STABLE** | STABLE | STABLE | --- | STABLE | STABLE | STABLE |

**Note:**
* GEN-2006-044 GE1.5MW Wind machines tripped on these faults. System remains stable with Trip disable on these machines.
** Oscillations observed in wind farms connected at bus #90100 and #90103. These oscillations are eliminated with reduced GEN-2006-044 generation to 370 MW.

# 3 CONCLUSIONS

The objective of this study is to evaluate the impact of the proposed GEN-2006-044 wind farm on the stability of SPP system. The study is performed for two system scenarios: the 2008 Winter Peak and the 2012 Summer Peak.

The system was unstable following faults at or near the POI after interconnection of the proposed project. The same faults were stable in the pre-project cases. Two options were studied for GEN-2006-044 interconnection. First was with reduced MW generation from GEN-2006-044 and second with the full MW with addition of new line from GEN-2002-008 to Mooreland.

The system becomes stable with 170 MW output from the GEN-2006-044, but with tripping of GEN-2006-044 wind generators on under-voltage. No further reduction helps to avoid tripping of the wind generators. However, the system remains stable with tripping disabled on these machines. If the Holcomb-Finney 345 kV line outage is mitigated, then the GEN-2006-044 generation limit increases to 370 MW with no additional upgrades.

A new 345 kV line from GEN-2002-008 Station to Mooreland was shown to be an acceptable solution for all specified faults with the full 400 MW generation from GEN-2006-044.

**FERC Order 661A Compliance** – With the new 345 kV line from GEN-2002-008 station to Mooreland, the GEN-2006-044 wind farm with GE 1.5 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