Southwest Power Pool

Impact Study for Generation Interconnection Request GEN–2006–021 Restudy

SPP Tariff Studies
(#GEN-2006-021)

October 2007

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP), ABB Grid Systems Consulting (ABB) performed the following Impact Study to satisfy the Impact Study Agreement executed by the requesting customer and SPP for SPP Generation Interconnection request GEN-2006-021. The request for interconnection was placed with SPP in accordance SPP's Open Access Transmission Tariff, which covers new generation interconnections on SPP's transmission system.

The Interconnection Customer has requested a restudy of the GEN-2006-021 Impact Study. The Customer is not changing wind turbines, but has asked for the reactive compensation requirements for the 250 MW wind farm to be revisited if the wind farm operates initially at 100 MW.

The Impact Study has determined that a 34.5kV capacitor bank of 12 Mvar is necessary for 100 MW operation. This capacitor bank shall be a staged bank with at least four stages for necessary voltage profiling of the wind farm during normal operation. The wind farm should operate at a unity power factor during normal operation, but may be allowed to switch capacitors in and out during abnormal operation to maintain proper system voltage levels.

The Impact Study has determine that for 100 MW operation, the wind farm equipped with Clipper Liberty 2.5 MW wind turbines, will comply with FERC Order #661A's low voltage ride through provisions without an SVC or STATCOM device.

Based on the dynamic wind turbine model provided by the Customer, with proper de-energized tap changer setting, LTC settings, and staged capacitor bank switching coordination, an SVC or STATCOM device will not be required for 100 MW operation. If any of these coordination conditions cannot be met and the wind farm creates operational problems for the Transmission Owner due to voltage and reactive power swings, a STATCOM device may be required at a later time.

The original Impact Study SVC requirements of two (2) +/-50 Mvar SVC will still be required for the full 250 MW wind farm if no new transmission reinforcements are built.

For more information on the GEN-2006-021 wind farm, please consult the original Impact Study posted in June 2007 and the Facility Study posted in October 2007 for GEN-2006-021.

POWER SYSTEMS DIVISION
GRID SYSTEMS CONSULTING

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2006-021 Restudy

FINAL REPORT

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ABB Inc – Grid Systems Consulting

Technical Report

Southwest Power Pool	**No.** 2006-11618-R0	
Impact Study for Generation Interconnection request GEN-2006-021 Restudy	10/23/2007	# Pages 22

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Executive Summary

Southwest Power Pool (SPP) has commissioned ABB to perform a restudy of the Generation Interconnection Impact study of a new wind farm in Harper County, Kansas, GEN-2006-021. The original study was for a 250 MW wind farm. This restudy is for a smaller wind farm size of 100 MW. A new 6 mile 138 kV transmission line will connect the wind farm to the West Plains Electric transmission system. The new line will tap into the Medicine Lodge – Harper 138 kV transmission line, at a point approximately 26% of the distance from Medicine Lodge. The wind farm itself will consist of a 34.5 kV collector system with 40 Clipper 2.5 MW wind turbines.

The interconnection impact study includes only stability analysis. A 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 GEN-2006-021 and to determine its effect on the nearby transmission system and generating stations. The study is performed for two system scenarios: 2007 Winter Peak and the 2011 Summer Peak.

The GEN-2006-021 wind farm will need to add 12 Mvar of capacitors at its substation 34.5 kV bus to maintain the POI power factor close to 1.0. Under high voltage conditions in the wind farm or transmission system, some of these may have to be switched off.

The original power flow model used a 0.975 tap setting on the low side of the GEN-2006-021 138/34.5 kV substation transformer, and post-contingency, steady-state high voltage caused tripping of GEN-2006-021 following loss of the 138 kV line to Medicine Lodge. When the tap was changed to 0.95, GEN-2006-021 did not trip for any of the simulated faults and everything was stable in Summer Peak and Winter Peak simulations. Unlike the study of GEN-2006-021 at 250 MW, no SVCs or STATCOMs are needed for GEN-2006-021 to operate up to 100 MW, as long as tap settings are chosen appropriately.

Based on the results of stability analysis it can be concluded that the proposed GEN-2006-021 project would not adversely impact the stability of the SPP system if the wind generation output is limited to 100 MW or less.

Rev No.	Revision Description	Date	Authored by	Reviewed by	Approved by
0	Final Report	10/23/2007	Ghassan Simaan	Bill Quaintance	Willie Wong
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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 the GEN-2006-021 wind farm in Harper County, Kansas. ABB Consulting previously completed an Impact study for GEN-2006-021 at a 250 MW capacity (Impact Study for Generation interconnection Request GEN-2006-021). Per the developer's request, a restudy has been performed for a reduced capacity of 100 MW. The interconnection impact study includes only stability analysis. A 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-2006-021 plant and to determine its effect on the nearby transmission system and generating stations. The study is performed for two system scenarios: the 2007 Winter Peak and the 2011 Summer Peak.

A new 6 mile 138 kV transmission line will connect the wind farm to the West Plains Electric transmission system. The new line will tap into the Medicine Lodge – Harper 138 kV transmission line, at a point approximately 26% of the distance from Medicine Lodge. The 100 MW plant will have a 34.5 kV collector system with 40 Clipper 2.5 MW wind turbines.

2 STABILITY ANALYSIS

In this 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. Most of the simulations represent three-phase or single-phase faults cleared by primary protection in 5 cycles, re-closing after 20 more cycles with the fault still on, and then permanently clearing the fault 5 cycles later with primary protection.

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 asynchronous with the system) 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 V29. 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.

2.2 STUDY MODEL DEVELOPMENT

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

Power Flow Cases

The pre-project cases from the original GEN-2006-021 study at a 250 MW capacity were used again as the pre-project cases for this restudy. Figure 2.2-1 and Figure 2.2-2 show the power flow diagrams for the local area without the proposed GEN-2006-021 project.

The proposed GEN-2006-021 project will consist of 40 Clipper 2.5 MW wind turbine generators for a total 100 MW output. The plant will be connected to the Medicine Lodge – Harper 138 kV transmission line by a new 6-mile transmission line and two two-winding 138/34.5 kV transformers.

The post-project cases developed for the original GEN-2006-021 study at a 250 MW capacity (‘*SP021.SAV*’ for 2012 Summer Peak and ‘*WP021.SAV*’ for Winter Peak 2007) were modified for this restudy. The original 250 MW wind farm consisted of two 138/34.5 kV transformers, each fed by a separate collector system and 125 MW of wind turbines. The transformer fed by the *longer* collector system was disconnected for this restudy, along with its equivalent generator, GSU transformer, and collector impedance. The equivalent generator, GSU transformer, and collector impedance of the *remaining* side were adjusted to represent a 100 MW capacity instead of 125 MW. Per the developer’s instructions, the substation transformer and 138 kV radial transmission line were not adjusted since the developer plans to eventually build out the entire 250 MW. The detailed process of wind farm model development is described in Appendix A.

To maintain unity power factor at the POI (138kV side), 12 Mvar of shunt capacitors are required on the 34.5kV side of the wind farm. However, for the conditions modeled in this study, the amount of capacitors modeled as on-line was reduced to keep the 138 kV voltages from exceeding 1.05 pu. The capacitors on-line for the restudy were 10 Mvar for the 2007 Winter case and 9 MVAR in the 2011 Summer case.

The SPP generation dispatch in areas 502 520 523 524 525 526 540 541 544 546 was readjusted to match the 100 MW level. See Table2-1. Two power flow cases with GEN-2006-021 were thus established:

- *SP021-restudy.SAV – the 2011 summer peak post-project case*
- *WP021-restudy.SAV – the 2007 winter peak post-project case*

Figure 2.2-3 and Figure 2.2-4 show the Power flow diagram for the local area with the proposed project connected at 100 MW output level.

Table 2-1: GEN-2006-021 project details

System condition	MW	Location	Point of Interconnection	Sink
Summer Peak	100	Harper County, Kansas	Medicine Lodge - Harper 138 kV transmission line	Areas 502 520 523 524 525 526 540 541 544 546
Winter Peak	100	Harper County, Kansas	Medicine Lodge - Harper 138 kV transmission line	Areas 502 520 523 524 525 526 540 541 544 546

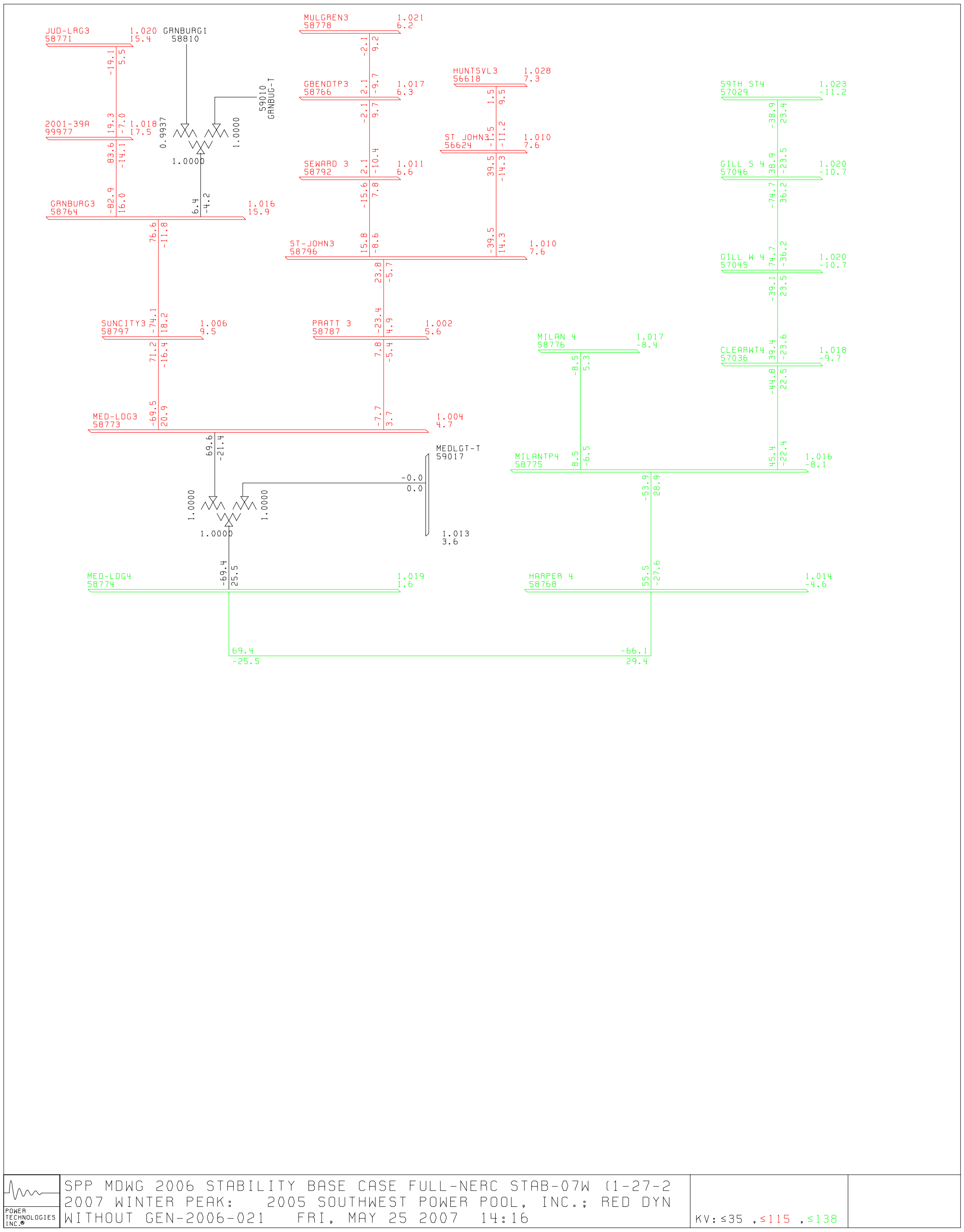

Figure 2.2-1 Winter 2007 Peak Flows and Voltages Without GEN-2006-021

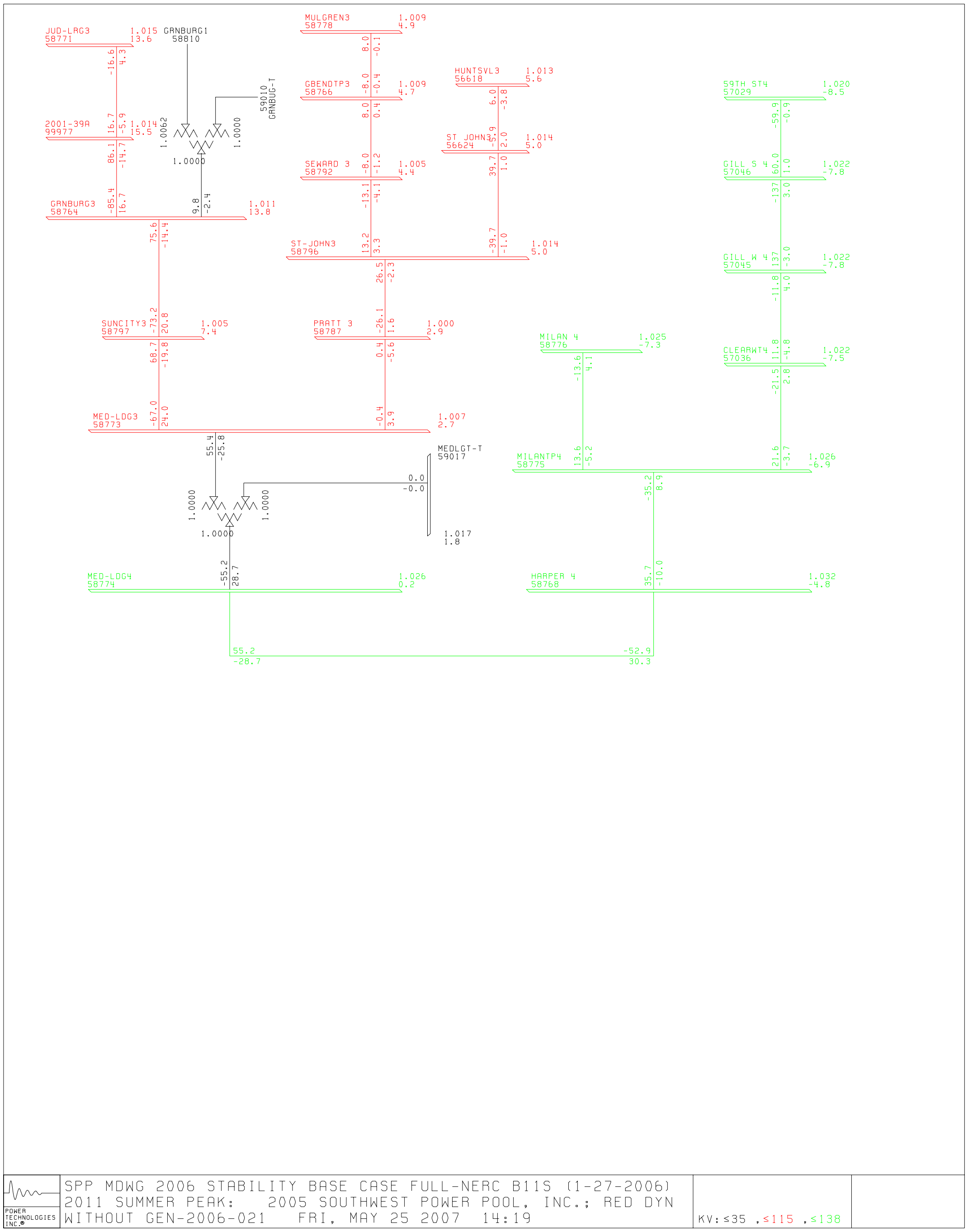

Figure 2.2-2 Summer 2011 Peak Flows and Voltages Without GEN-2006-021

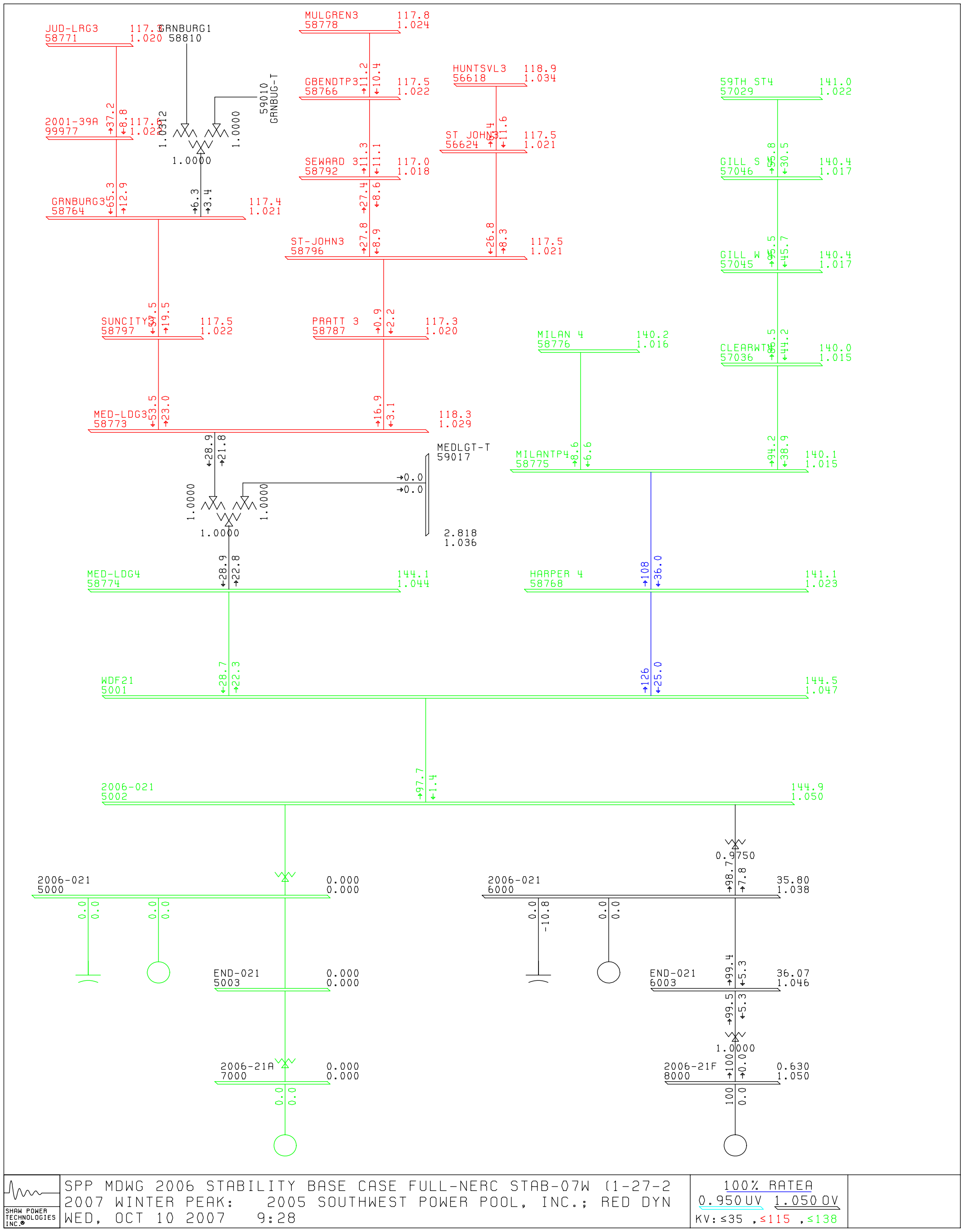

Figure 2.2-3 Winter 2007 Peak Flows and Voltages With GEN-2006-021 at 100 MW

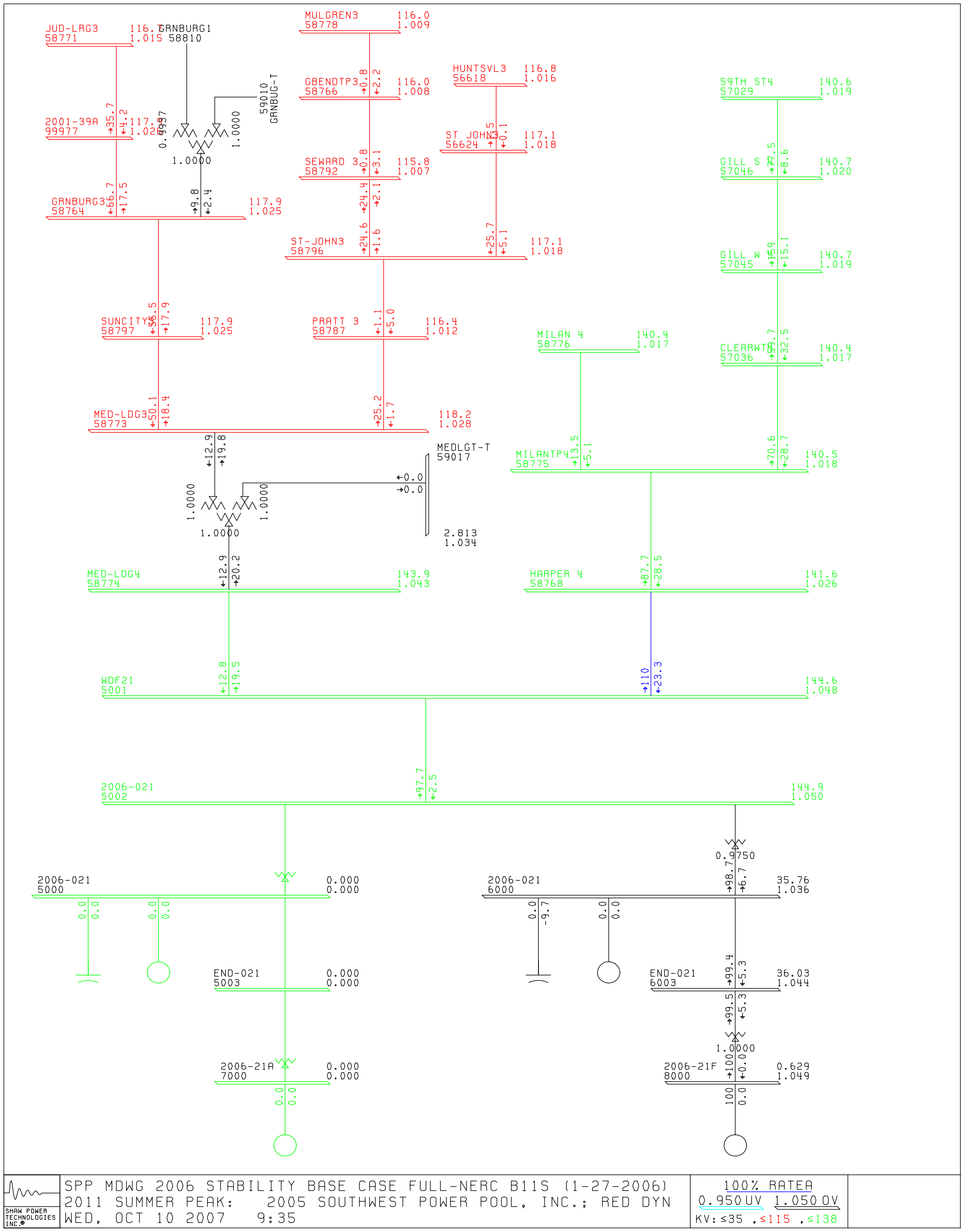

Figure 2.2-4 Summer 2011 Peak Flows and Voltages With GEN-2006-021 at 100 MW

Stability Database

The stability databases developed for the original GEN-2006-021 study were used as the starting point. The dynamics data for the remaining equivalent generator was adjusted to 100 MVA base for this restudy. The power flow and stability model representations for GEN-2006-021 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 5 seconds.

Table 2-1: List of Faults for Stability Analysis

FAULT	FAULT DESCRIPTION
FLT_1_3PH	a. Apply a 3-phase fault at the POI (bus 5001) on the 138 kV line to Medicine Lodge. b. Clear fault after 5 cycles by removing the line from 5001 to 58768. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_2_1PH	a. Apply 1-phase fault at the POI (bus 5001) on the 138 kV line to Medicine Lodge. b. Clear fault after 5 cycles by removing the line from 5001 to 58758. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_3_3PH	a. Apply 3-phase fault at the POI (bus 5001) on the 138 kV line to Harper. b. Clear fault after 5 cycles by removing the line from 5001 to 58768. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_4_1PH	a. Apply 1-phase fault at the POI (bus 5001) on the 138 kV line to Harper. b. Clear fault after 5 cycles by removing the line from 5001 to 58768. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_5_3PH	a. Apply 3-phase fault at the Pratt 115 kV bus (58787) on the line to St John. b. Clear fault after 5 cycles by removing the line from 58787 to 58796. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_6_1PH	a. Apply 1-phase fault at the Pratt 115 kV bus (58787) on the line to St John. b. Clear fault after 5 cycles by removing the line from 58787 to 58796. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_7_3PH	a. Apply 3-phase fault at the Judson Large 115 kV bus (58771) on the line to GEN-2001-039A. b. Clear fault after 5 cycles by removing the line from 58771 to 99977. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_8_1PH	a. Apply 1-phase fault at the Judson Large 115 kV bus (58771) on the line to GEN-2001-039A. b. Clear fault after 5 cycles by removing the line from 58771 to 99977. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.

FAULT	FAULT DESCRIPTION
FLT_9_3PH	a. Apply 3-phase fault at the Medicine Lodge 115 kV bus (58773) on the line to Sun City (58797). b. Clear fault after 5 cycles by removing the line from 58773 to 58797. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_10_1PH	a. Apply 1-phase fault at the Medicine Lodge 115 kV bus (58773) on the line to Sun City (58797). b. Clear fault after 5 cycles by removing the line from 58773 to 58797. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_11_3PH	a. Apply 3-phase fault at the Medicine Lodge 115 kV bus (58773) on the line to Pratt (58787). b. Clear fault after 5 cycles by removing the line from 58773 to 58787. c. Wait 20 cycles, and then re-close the 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 Medicine Lodge 115 kV bus (58773) on the line to Pratt (58787). b. Clear fault after 5 cycles by removing the line from 58773 to 58787. c. Wait 20 cycles, and then re-close the 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 Kinsley Tap 230 kV bus (100) on the line to Spearville (58795). b. Clear fault after 5 cycles by removing the line from 100 to 58795. c. Wait 20 cycles, and then re-close the 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 Kinsley Tap 230 kV bus (100) on the line to Spearville (58795). b. Clear fault after 5 cycles by removing the line from 100 to 58795. c. Wait 20 cycles, and then re-close the 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 Kinsley Tap 230 kV bus (100) on the line to Mullergren (58779). b. Clear fault after 5 cycles by tripping the line from bus 100 to 58779. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove the fault.
FLT_16_1PH	a. Apply 1-phase fault at the Kinsley Tap 230 kV bus (100) on the line to Mullergren (58779). b. Clear fault after 5 cycles by tripping the line from bus 100 to 58779. c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove the fault.
FLT_17_3PH	a. Apply 3-phase fault at the Kinsley Tap 230 kV bus (100). b. Clear fault after 5 cycles by tripping the autotransformer (56619).
FLT_18_1PH	a. Apply 1-phase fault at the Medicine Lodge 115 kV bus (58773) on the line to Sun City. b. After 7 cycles open the Medicine Lodge breaker. c. After 20 cycles, open the Sun City (58797) to Greenburg (58764) line clearing the fault.

2.3 STUDY RESULTS

The results for the simulated disturbances are summarized in Table 2-3. Plots showing the simulation results are included in Appendices C and D.

The faults were initially run to t=5s. In the resulting plots, it could be seen that the voltage at the terminal of the GEN-2006-021 wind generator settled out to a steady-state value above 110% for faults 1 and 2. Both of these faults involve the outage of the 138 kV line from the GEN-2006-021 POI to Medicine Lodge, leaving the wind farm hanging on the relatively long weak line to Harper. Based on the wind turbine model documentation, the Clipper wind turbines will trip if the voltage stays above 110% for 5 sec. Faults 1 and 2 were rerun to t=10s, and indeed the GEN-2006-021 wind generator does trip offline due to the high voltage. This is not really a transient or stability issue, but more of a steady-state, post-contingency, high-voltage problem, as was confirmed by testing the contingencies in the power flow case.

A solution to preventing this high voltage at the wind turbines is by adjusting the tap setting of the 138/34.5 wind farm substation transformer in the base cases. There is nothing magic about the original setting chosen for the original post-project power flow cases. At a tap of 1.0, the wind farm voltages were above 1.05, so the 34.5 kV tap was adjusted down by 2.5% to bring the wind farm voltages down to 1.05 or below. Tapping down another 2.5% will give wind farm voltages in the range of 1.0 to 1.02 (see Figures 2.3-1 and 2.3-2). The resulting tap setting is 0.95 on the 34.5 kV side. The same effect could be achieved by using a 1.05 tap setting on the 138 kV side.

After changing the base case tap to 0.95 on the 34.5 kV side of the GEN-2006-021 substation transformer, all simulations were rerun. The GEN-2006-021 generator did not trip for any of the simulations with the modified base case tap setting, and everything else was stable. This demonstrates that the transformer tap setting will need to be coordinated with the potential for high voltage at the POI.

Note that the capacitors on the 34.5 kV bus were on-line during these simulations, but they should be switched off when the 138 kV bus voltage goes too high. However, this does not need to be faster than normal (e.g. 30 sec) if the transformer tap is set appropriately. Alternatively, the capacitors could be set to trip quickly when voltages go too high.

Under-voltage tripping of a prior-queued wind farm at 58867 HAGGARD2 34.5 was found for Fault 7 in summer peak and winter peak cases. Fault 7 was repeated in the pre-project cases, and the same tripping occurred, making this a pre-existing issue.

Table 2-2: Results of Initial Stability Simulations

FAULT	Winter Peak 2007 with 0.975 tap	Summer Peak 2011 with 0.975 tap	Winter Peak 2007 with 0.95 tap	Summer Peak 2011 w with 0.95 tap
FLT_1_3PH	STABLE GEN-2006-021 trips on high voltage	STABLE GEN-2006-021 trips on high voltage	STABLE	STABLE
FLT_2_1PH	STABLE GEN-2006-021 trips on high voltage	STABLE GEN-2006-021 trips on high voltage	STABLE	STABLE
FLT_3_3PH	STABLE	STABLE	STABLE	STABLE
FLT_4_1PH	STABLE	STABLE	STABLE	STABLE
FLT_5_3PH	STABLE	STABLE	STABLE	STABLE
FLT_6_1PH	STABLE	STABLE	STABLE	STABLE
FLT_7_3PH	STABLE[1]	STABLE[1]	STABLE[1]	STABLE[1]
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

[1] Wind generator at bus 58867 HAGGARD2 34.5 tripped on low voltage

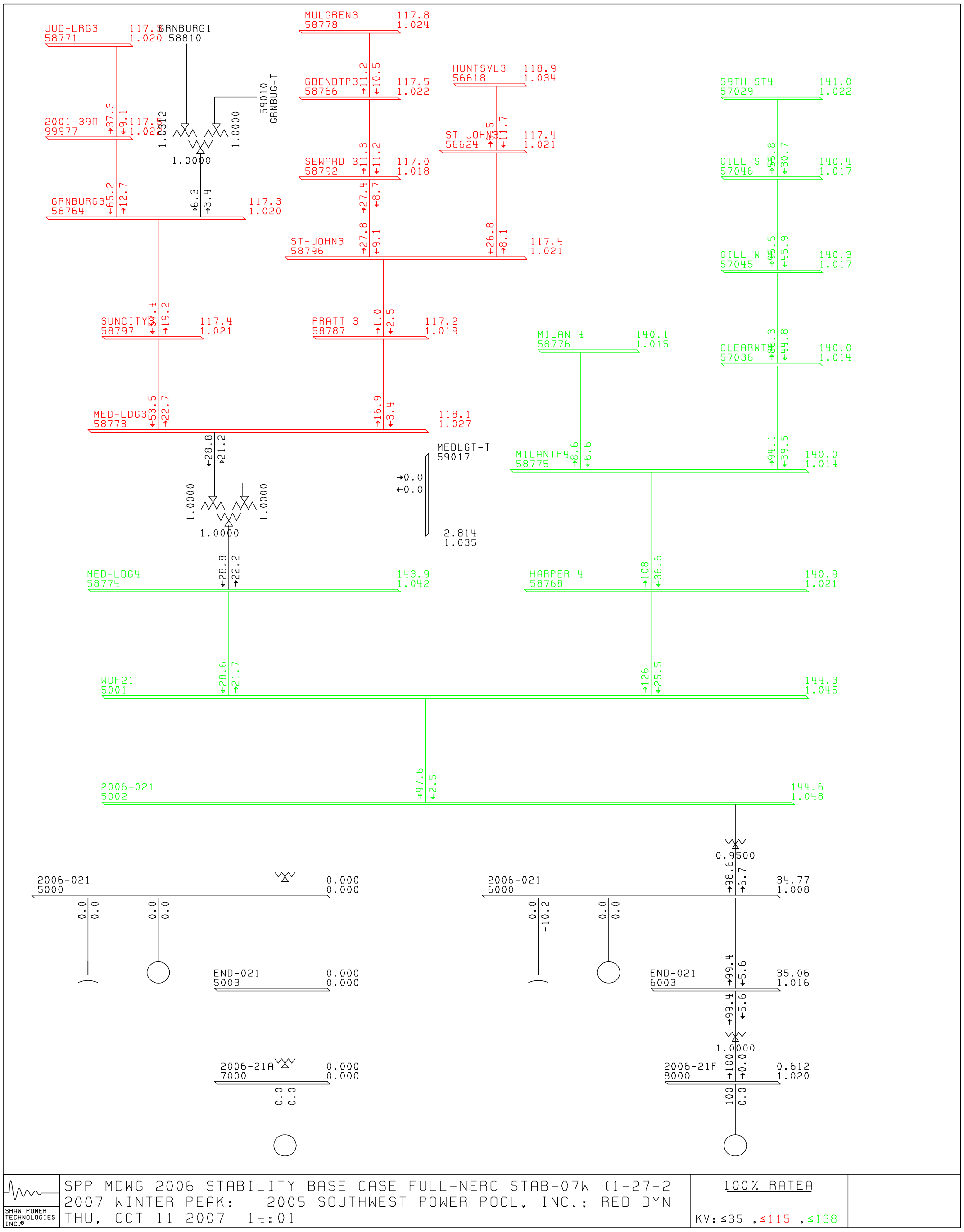

Figure 2.3-1 Winter 2007 Case with 0.95 Tap

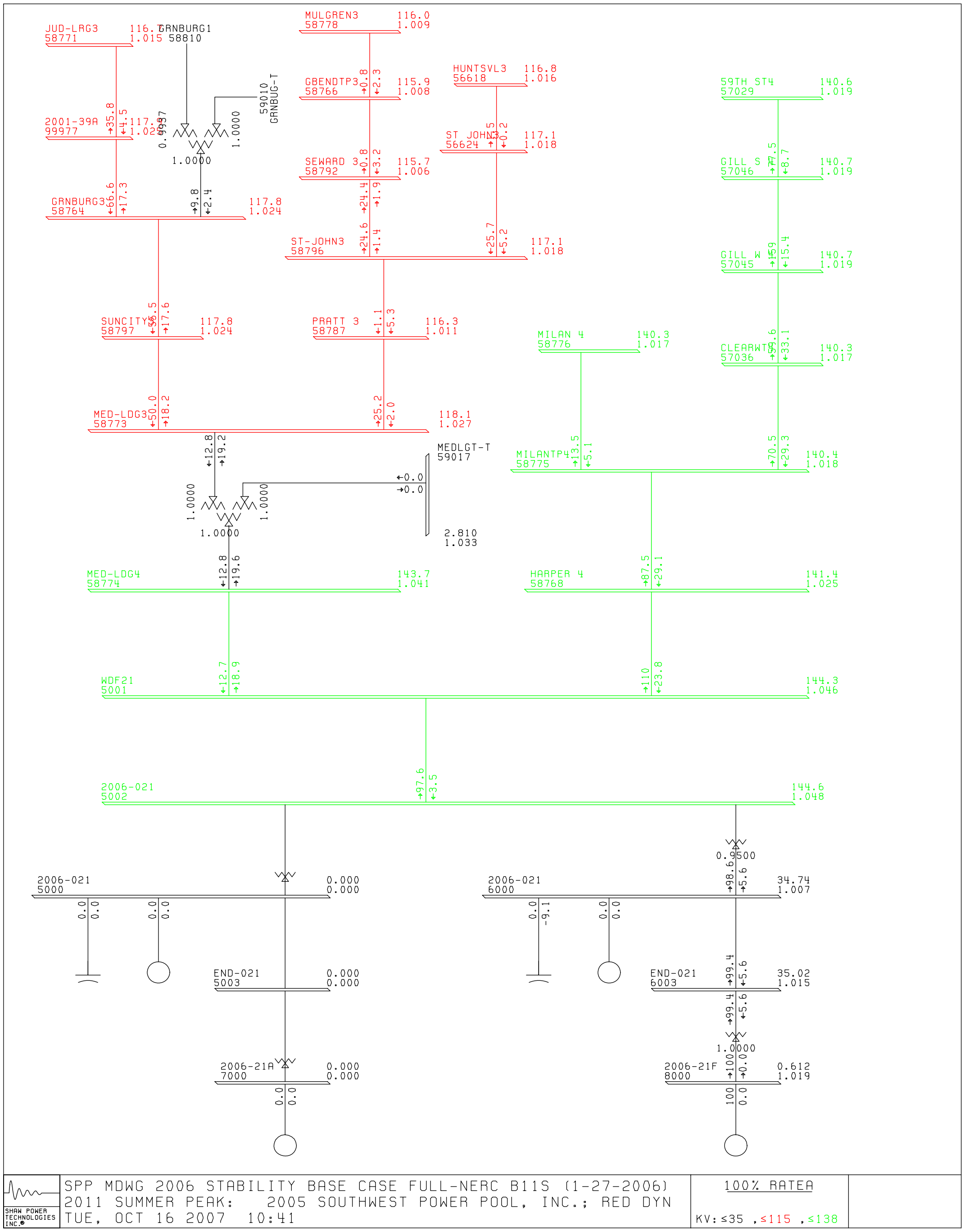

Figure 2.3-2 Summer 2011 Case with 0.95 Tap

3 CONCLUSIONS

The objective of this Restudy was to evaluate power system stability with the GEN-2006-021 wind plant reduced to 100 MW from 250 MW. The study was performed for two system conditions: 2007 Winter Peak and 2011 Summer Peak.

The GEN-2006-021 wind farm will need to add 12 Mvar of capacitors at its substation 34.5 kV bus to maintain the POI power factor close to 1.0. Under high voltage conditions in the wind farm or transmission system, some of these may have to be switched off.

The original power flow model used a 0.975 tap setting on the low side of the GEN-2006-021 138/34.5 kV substation transformer, and post-contingency, steady-state high voltage caused tripping of GEN-2006-021 following loss of the 138 kV line to Medicine Lodge. When the tap was changed to 0.95, GEN-2006-021 did not trip for any of the simulated faults and everything was stable in Summer Peak and Winter Peak simulations. Unlike the study of GEN-2006-021 at 250 MW, no SVCs or STATCOMs are needed for GEN-2006-021 to operate up to 100 MW, as long as tap settings are chosen appropriately.

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 - STABILITY PLOTS WITH 0.975 TAP SETTING

APPENDIX D - STABILITY PLOTS WITH 0.95 TAP SETTING