Southwest Power Pool

Impact Study for Generation Interconnection Request GEN–2006–022

SPP Tariff Studies
(#GEN-2006-022)

August 21, 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-2006-022. 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.

Facilities

The Impact Study determined that to interconnect the 150 MW wind farm with the Clipper 2.5MW wind turbines in the Pratt – St. John 115kV line with no transmission reinforcements and with prior queued projects in service will require the addition of a -25/+75 MVar Static Var Compensator (SVC) on the 34.5kV bus of the Customer 115/34.5kV interconnection substation. Also required is a 34.5kV, seventeen (17) MVar capacitor bank on the 34.5kV bus of the Customer substation.

This SVC device and its size are necessary for a combination of reasons. The first reason is the need for the wind farm to meet FERC Order #661A for low voltage ride through considerations. The second reason is that enough capacitors cannot be installed at the wind farm before it causes voltages to be excessively high during system intact conditions. These conditions occur because of insufficient transmission facilities in the area of the generation interconnection request to deliver the requested output of 150MW into the transmission system along with previous queued projects in the local area. Prior queued project GEN-2006-021 (250MW) is also in close proximity to this generation interconnection request and is affecting the size of this SVC. With adequate transmission system reinforcements that can be determined through a Transmission Service Request (TSR), the size of the SVCs may be re-evaluated.

The Customer may ask for a restudy of the SVC requirements for this generation interconnection request if the transmission reinforcements in the area change due to a TSR made by the Customer or on the Customer's behalf.

The requirements for interconnection of the 150MW consist of building a new 115kV three breaker ring bus substation at a point close to the existing Mid Kansas Electric Corp. (MKEC) (former West Plains Electric) Pratt substation. This substation will be electrically between St. John and Pratt. This 115kV substation shall be constructed and maintained by MKEC. The Customer did not propose a route of its 115kV line to serve its 115/34.5kV facilities. It is assumed that obtaining all necessary right-of-way for the substation construction will not be a significant expense.

The total cost for building a new 115kV 3-breaker ring switching station, the required interconnection facilities, was estimated in the Feasibility Study at $4,272,581. Please see the Feasibility Study for a more detailed description of this facility.

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

Table 1: Direct Assignment Facilities

Facility	ESTIMATED COST (2007 DOLLARS)
Customer – 115-34.5 kV Substation facilities.	*
Customer – 115kV transmission line facilities between Customer facilities and MKEC 115kV switching station	*
Customer - Right-of-Way for Customer facilities.	*
Customer – 34.5kV, 17Mvar capacitor bank in Customer substation	*
Customer – +75/-25Mvar Static Var Compensator (SVC) Device	
Total	*

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

Table 2: Required Interconnection Network Upgrade Facilities

Facility	ESTIMATED COST (2007 DOLLARS)
MKEC – Build 115kV, 3-breaker ring bus switching station. Station to include breakers, switches, control relaying, high speed communications, all structures and metering and other related equipment	$3,560,484
Contribution in Aid of Construction (CIAC)	$712,097
Total	**$4,272,581**

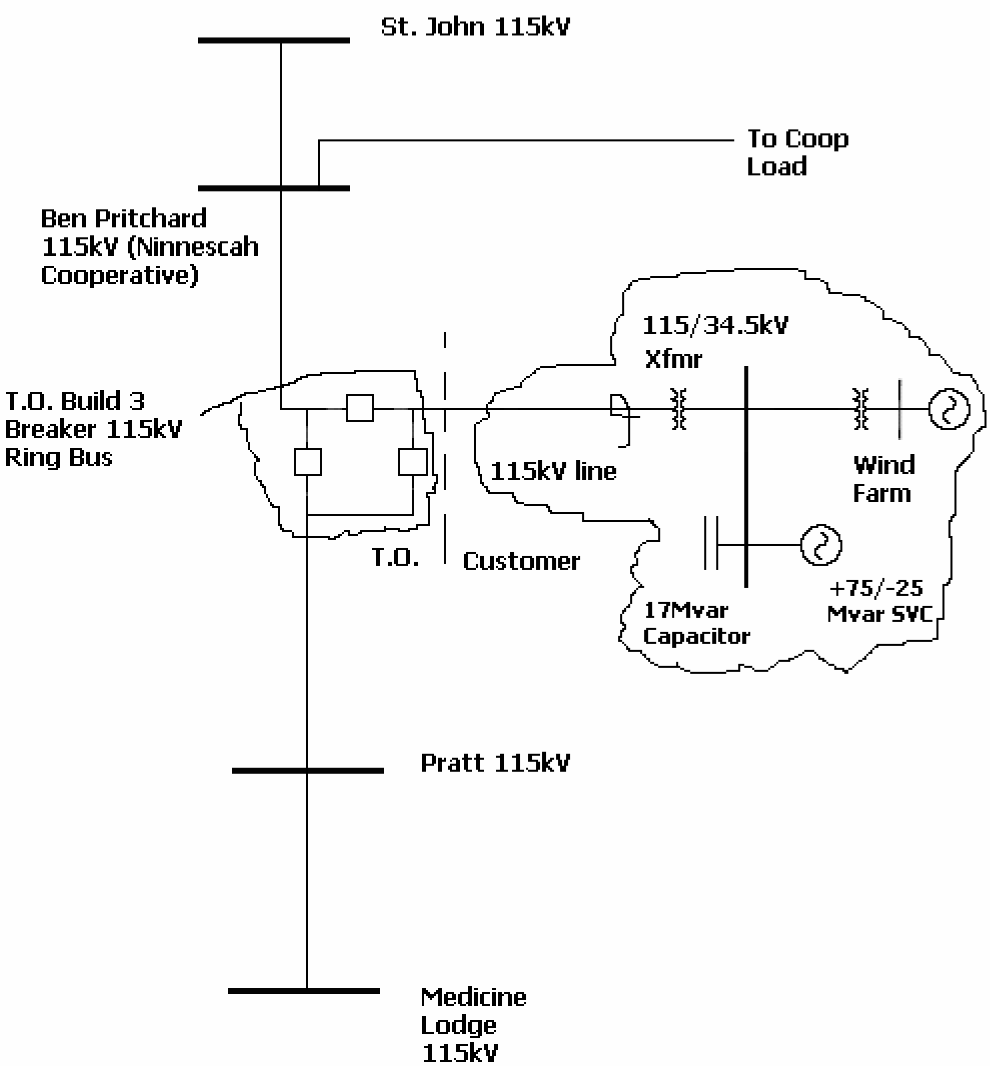

Figure 1: Proposed Interconnection
(Final substation design to be determined

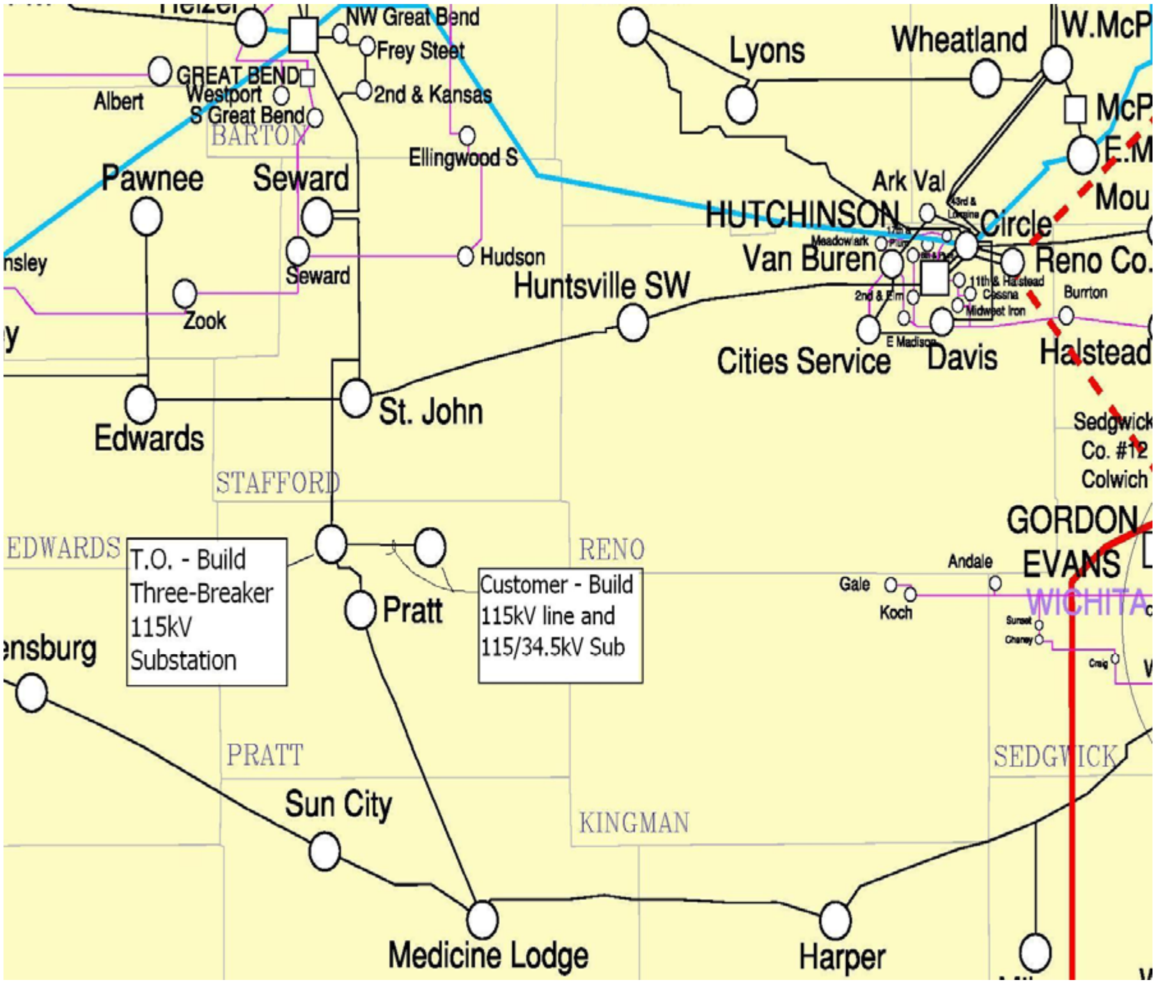

Figure 2: Map of the Local Area

POWER SYSTEMS DIVISION
GRID SYSTEMS CONSULTING

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2006-022

FFINAL REPORT

REPORT NO.: 2007-11562-R0
Issued: August 21, 2007

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ABB Inc – Grid Systems Consulting

Technical Report

Southwest Power Pool	**No.** 2007-11562-R0	
Impact Study for Generation Interconnection request GEN-2006-022	8/21/2007	# Pages 24

Author(s):	**Reviewed by:**	**Approved by:**
Bradley Johnson	Bill Quaintance	Willie Wong

Executive Summary

Southwest Power Pool (SPP) has commissioned ABB to perform a Generation Interconnection Impact study of a new 150 MW wind farm in Pratt County, Kansas (GEN-2006-022). A new ten mile 115 kV transmission line will connect the wind farm to the existing transmission system. The new line will tap into the Medicine Lodge – Pratt 115 kV transmission line close to the Pratt end. The plant itself will have a 34.5 kV collector system with 60 Clipper 2.5 MW wind turbines.

This 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 system dynamic response with GEN-2006-022 connected, and to determine its effect on the nearby transmission system and generating stations. The study is performed for the 2007 Winter Peak and the 2011 Summer Peak conditions.

For both load levels, adding enough shunt capacitors to bring the POI power factor to 1.0 would increase the 115 kV voltage above 1.05 pu, which is not acceptable. The recommended level of shunt capacitors is reduced to 17 Mvar at the GEN-2006-022 substation 34.5 kV bus to prevent the 115 kV bus voltage from going above 1.05 pu.

For the 2011 Summer Peak conditions and the 2007 Winter Peak conditions, the system response is unacceptable for the following faults if the wind farm is simulated without adding dynamic reactive compensation (e.g. an SVC):

- FLT_19_3PH (a three phase fault with unsuccessful re-closing, resulting in the loss of the Harper – GEN-2006-021 POI kV 138 kV circuit)
- FLT_20_1PH (a single phase fault with unsuccessful re-closing, resulting in the loss of the Harper – GEN-2006-021 POI 138 kV line)

For these faults there would be extremely high voltage excursions at the GEN-2006-022 wind plant, at other nearby plants, and in the 138 kV and 115 kV network; and the wind turbines will trip off-line.

Rev No.	Revision Description	Date	Authored by	Reviewed by	Approved by
0	Draft Report	8/21/2007	Bradley Johnson	Bill Quaintance	Willie Wong
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For the other simulated faults the system response is acceptable, GEN-2006-022 generators remain on-line, and the SPP system is stable for both the 2011 Summer Peak and 2007 Winter Peak conditions.

When a static var compensator (SVC) with a –25 MVAR to +75 MVAR range is connected to the wind farm's 34.5 kV bus, the system response is acceptable for all of the simulated faults including FLT_19_3PH and FLT_20_1PH; the GEN-2006-022 generators do not trip and the system is stable. Simulations of FLT_19_3PH with a smaller SVC (-25 to +50 MVAR) indicate that the smaller SVC would not suffice.

The proposed GEN-2006-022 project does not adversely impact the stability of the SPP system if a –25 MVAR to +75 MVAR SVC is added to the 34.5 kV substation bus, in addition to 17 Mvar of shunt capacitors.

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

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1 INTRODUCTION

Southwest Power Pool (SPP) has commissioned ABB Inc. to perform a Generation Interconnection Impact study of a new 150 MW wind farm in Pratt County, Kansas. A new 10 mile 115 kV transmission line will connect the wind farm to the transmission system. The new line will tap into the Medicine Lodge – Pratt 115 kV transmission line, close to the existing Pratt substation. The plant will have a 34.5 kV collector system with 60 Clipper 2.5 MW wind turbines.

The interconnection impact study includes only the 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 systems dynamic response with the GEN-2006-022 plant connected, and to determine its effect on the nearby transmission system and generating stations. The study is performed for the 2007 Winter Peak and the 2011 Summer Peak conditions.

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 permanent clearing of the fault 5 cycles later with primary protection.

2.1 STABILITY ANALYSIS METHODOLOGY

Stability analysis was performed using Siemens-PTI's PSS/E^{TM} dynamics program Rev29. Three-phase and single-phase line faults were simulated for the specified durations, including re-closing; and the voltage, speed, synchronous machine rotor angles and other system and equipment variables were monitored. 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.

<u>Power Flow Case</u>

The pre-project cases used for this study of GEN-2006-022 are the post-project cases from the GEN-2006-021 study. Those cases were derived from "*gen06-21_07wp_base.sav*" and "*gen06-21_11sp_base.sav*", provided by SPP, by adding the GEN-2006-021 project. The GEN-2006-021 study showed a need to add two 50 Mvar SVCs to the GEN-2006-021 substation, one on each 34.5 kV bus, to maintain stability and keep the GEN-2006-021 wind turbines on line. These SVCs are included in the pre-project cases for this study of GEN-2006-022.

Figure 2.2-1 and Figure 2.2-2 show the local system flows and voltages calculated for the base cases with the GEN-2006-021 wind farm but before the GEN-2006-022 plant is added. Figure 2.2-1 is for the Winter peak conditions and Figure 2.2-2 is for the Summer peak conditions.

Wind Farm Power Flow Model

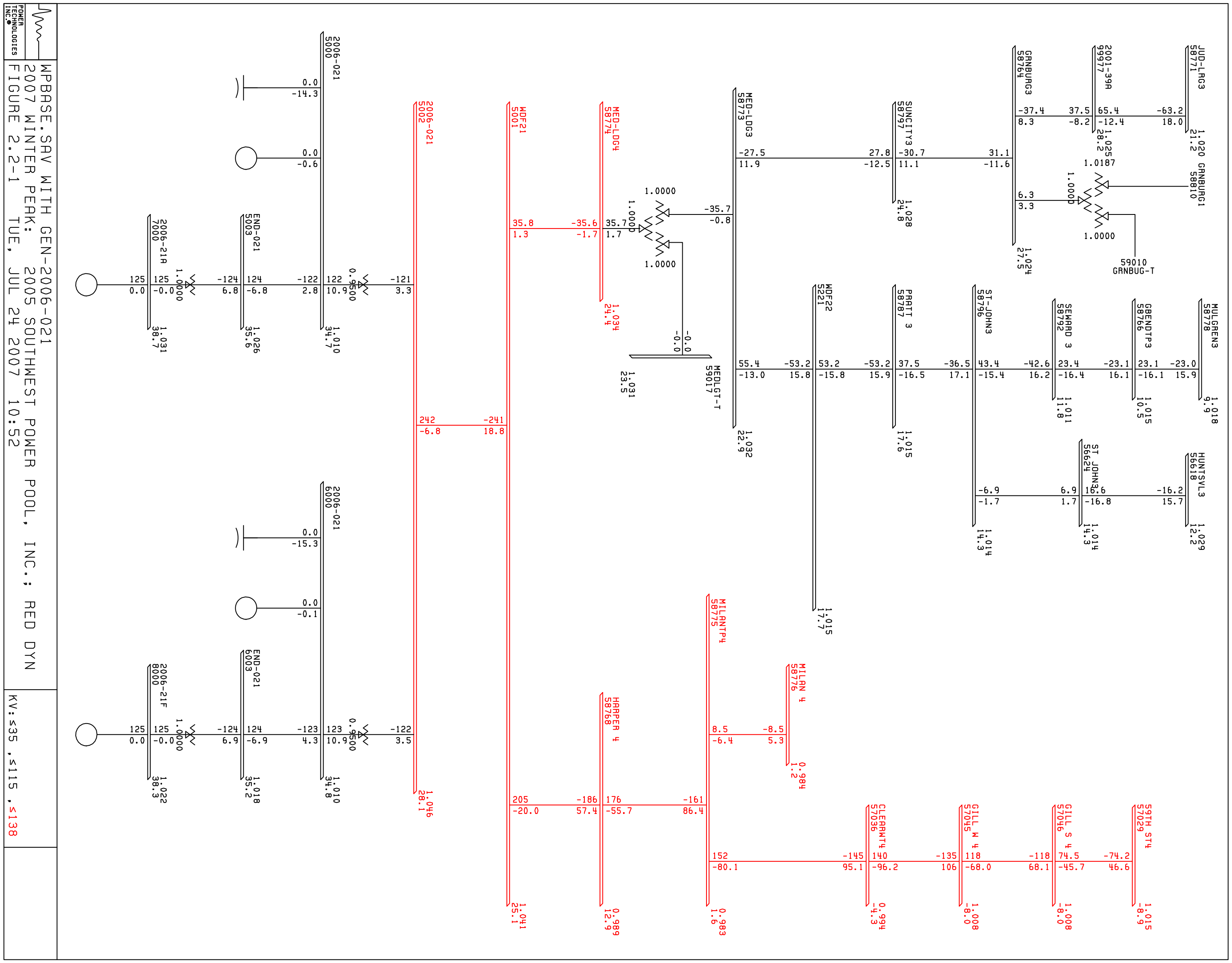
The plant will be connected to the Medicine Lodge – Pratt 115 kV transmission line by a new 10-mile transmission line and a two-winding 115/34.5 kV transformer. The proposed project was added to the Pre-project cases and the generation was redispatched by scaling down generation in areas 520, 524 and 544 by a total of 150 MW. See Table 2-1 for details. Two power flow cases with GEN-2006-022 were established:

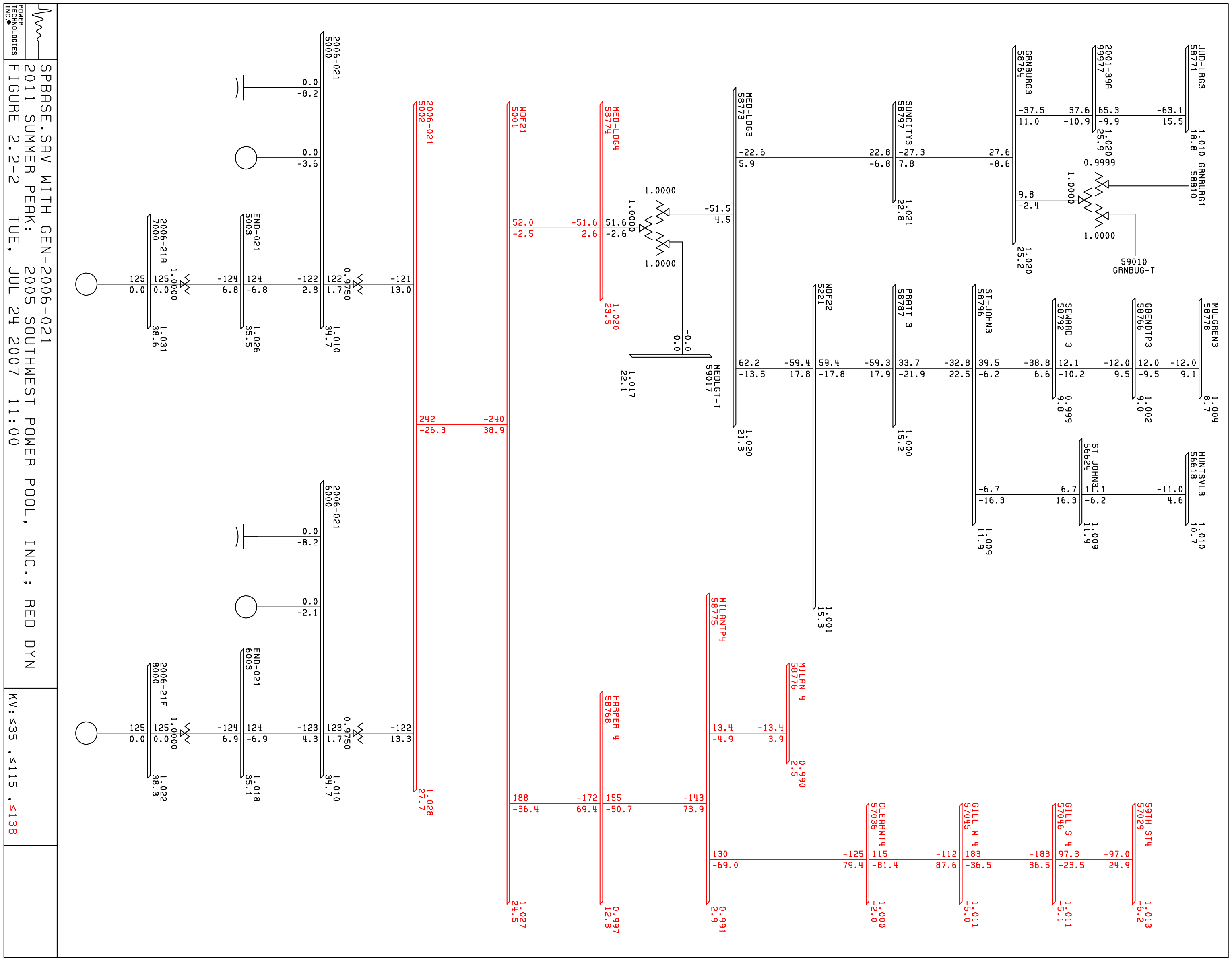
- *SP022.SAV – a 2011 summer peak case*
- *WP022.SAV – a 2007 winter peak case*

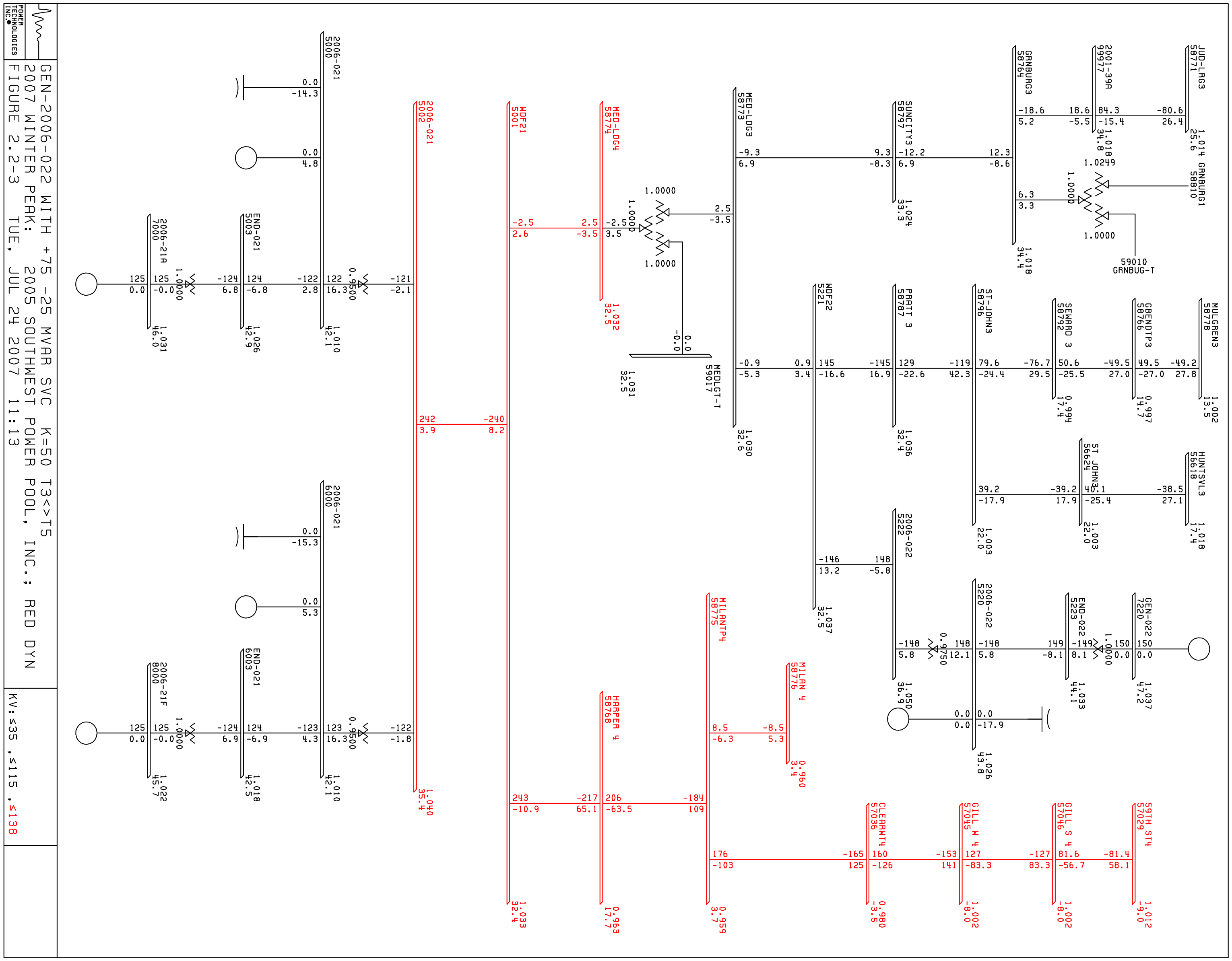
Table 2-1: GEN-2006-022 project details

System condition	MW	Location	Point of Interconnection	Sink
Summer Peak	150	Pratt County, Kansas	Medicine Lodge - Pratt 115 kV transmission line	Areas 520 524 544
Winter Peak	150	Pratt County, Kansas	Medicine Lodge - Pratt 115 kV transmission line	Areas 520 524 544

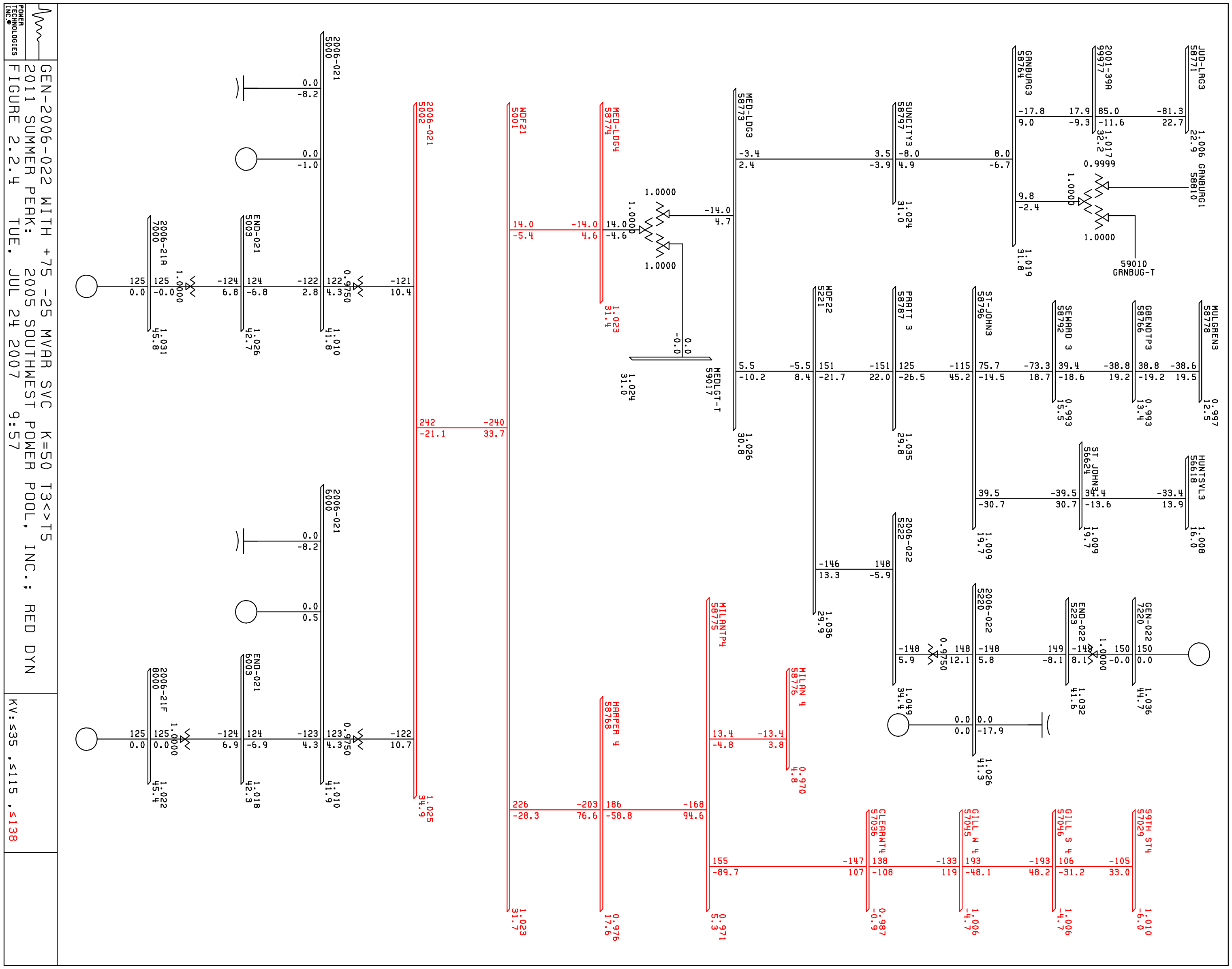
The GEN-2006-022 wind farm has 60 Clipper 2.5 MW wind turbine generators. An equivalent generator is used to model the 60 wind turbine-generators. The equivalent generator is connected to a 115/34.5 kV transformer through a single equivalent GSU transformer and a single equivalent collector branch. The 115/34.5 kV transformer is modeled explicitly and a new 10.0-mile 115 kV transmission line is represented to make the connection to the full SPP system model. The detailed process of wind farm model development is described in Appendix A. Figure 2.2-3 and Figure 2.2-4 show the local flows and voltages calculated with the GEN-2006-022 wind farm represented. Figure 2.2-3 is for the Winter peak conditions and Figure 2.2-4 is for the Summer peak conditions. For some of the simulations an SVC is attached to the wind farm at bus 5220. In Figure 2.2-3 and 2.2-4 the SVC output is zero.


WPBASE.SAV WITH GEN-2006-021
2007 WINTER PEAK: 2005 SOUTHWEST POWER POOL, INC.; RED DYN
FIGURE 2.2-1 TUE, JUL 24 2007 10:52
KV: ≤35 , ≤115 , ≤138


SPBASE.SAV WITH GEN-2006-021
2011 SUMMER PEAK: 2005 SOUTHWEST POWER POOL, INC.; RED DYN
FIGURE 2.2-2 TUE, JUL 24 2007 11:00
KV: ≤35 ,≤115 ,≤138


GEN-2006-022 WITH +75 -25 MVAR SVC K=50 T3<>T5
2007 WINTER PEAK: 2005 SOUTHWEST POWER POOL, INC.; RED DYN
FIGURE 2.2-3 TUE, JUL 24 2007 11:13
KV: ≤35 ,≤115 ,≤138

ABB


GEN-2006-022 WITH +75 -25 MVAR SVC K=50 T3<>T5
2011 SUMMER PEAK: 2005 SOUTHWEST POWER POOL, INC.; RED DYN
FIGURE 2.2.4 TUE, JUL 24 2007 9:57
kV: ≤35 , ≤115 , ≤138

Stability Database

As with the power flow cases, the pre-project stability models were taken from the post-project stability models of the GEN-2006-021 study. Those models were developed from "*gen06-21_11sp_base.dyr*" and "*gen06-21_07wp_base.dyr*", provided by SPP, by adding the GEN-2006-021 dynamic data. These files are compatible with PSS/E version 29.

ABB appended stability data to represent GEN-2006-022. The stability model incorporates the ride-through capability that allows wind turbine generator operation below 90% terminal voltage for up to 3 seconds and fast tripping (100 ms) for terminal voltages below 10%. The voltage trip settings are hard-coded in the model's FLECS code.

For some of the simulations, a static var controller (SVC) was represented on the GEN-2006-022 substation 34.5 kV bus. These were modeled using a standard PSS/E model, CSVGN4, which is also used for the SVCs at GEN-2006-021. During the simulated faults, the output admittances of these static var controllers are fixed by setting their time constant to a very large value. This emulates a control feature found on most static var controllers that blocks SVC output during fault conditions. Emulating this control action provides a more accurate representation of the expected SVC response during and immediately following the fault.

The power flow and stability model representations for GEN-2006-022 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 at least 2 seconds.

Table 2-2: List of Faults for Stability Analysis

FAULT	FAULT DESCRIPTION
FLT_1_3PH	a. Apply a 3-phase fault at the POI (bus 5221) on the 115 kV line to St John. b. Clear fault after 5 cycles by removing the line from 5221 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_2_1PH	a. Apply 1-phase fault at the POI (bus 5221) on the 115 kV line to St John. b. Clear fault after 5 cycles by removing the line from 5221 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_3_3PH	a. Apply 3-phase fault at the POI (bus 5221) on the 115 kV line to Medicine Lodge. b. Clear fault after 5 cycles by removing the line from 5221 to 58773. 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 5221) on the 115 kV line to Medicine Lodge. b. Clear fault after 5 cycles by removing the line from 5221 to 58773. 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_5_3PH	a. Apply 3-phase fault at the St John 115 kV bus (58796) on the line to Seward. b. Clear fault after 5 cycles by removing the line from 58796 to 58792. 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 St John 115 kV bus (58796) on the line to Seward. b. Clear fault after 5 cycles by removing the line from 58796 to 58792. 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.
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 St John 115 kV bus (56624) on the line to Edwards (56617). b. Clear fault after 5 cycles by removing the line from 56624 to 56617. 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 St John 115 kV bus (56624) on the line to Edwards (56617). b. Clear fault after 5 cycles by removing the line from 56624 to 56617. 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 St John 115 kV bus (56624) on the line to Huntsville (56618). b. Clear fault after 5 cycles by removing the line from 56624 to 556618. 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 St John 115 kV bus (56624) on the line to Huntsville (56618). b. Clear fault after 5 cycles by removing the line from 56624 to 56618. 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_15_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 tripping the line from bus 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 the fault.
FLT_16_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 tripping the line from bus 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 the fault.
FLT_17_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 fault.
FLT_18_1PH	a. Apply 1-phase fault at the Kinsley Tab 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. After 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_19_3PH	a. Apply 3-phase fault at the Harper 138 kV bus (58768) on the line to GEN-2006-021 (5001). b. Clear fault after 5 cycles by tripping the line from bus 58768 to 5001. 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_20_1PH	a. Apply 1-phase fault at the Harper 138 kV bus (58768) on the line to GEN-2006-021 (5001). b. Clear fault after 5 cycles by tripping the line from bus 58768 to 5001. 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_21_3PH	a. Apply 3-phase fault at the Mullergren 230 kV bus (58779) on the line to Circle (56871). b. Clear fault after 5 cycles by tripping the line from bus 58779 to 56871. 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_22_1PH	a. Apply 1-phase fault at the Mullergren 230 kV bus (58779) on the line to Circle (56871). b. Clear fault after 5 cycles by tripping the line from bus 58779 to 56871. 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_23_1PH	a. Apply 1-phase fault at the Medicine Lodge 230 kV bus (58774) on the line to Sun City (58797). b. After 7 cycles open breaker at Medicine Lodge. c. After 20 cycles, open Greenburg (58764) to Sun City line and remove fault.

2.3 STUDY RESULTS

2.3.1 BASE SIMULATIONS

For the initial series of simulations the wind plant was represented with enough fixed shunt compensation to maintain 1.05 per unit voltage at the 115 kV wind farm bus for the pre-fault condition. For both the Summer Peak and Winter Peak cases a voltage of 1.05 per unit can be maintained at the wind farm 115 kV bus by adding 17 MVAR of shunt capacitors at the GEN-2006-022 collector system 34.5 kV bus. The power factor at the point of interconnection (POI) is not corrected to 1.0, but any more reactive compensation would have pushed the 115 kV bus voltage over 1.05 pu. No SVC was represented in the GEN-2006-022 plant for the simulations discussed in this section.

The results for all of these simulated disturbances are summarized in Table 2-3. Plots showing key simulation results for all of the faults are included in Appendix C. For the simulations representing FLT_1_3, FLT_19_3, FLT_2_1, and FLT_20_1 more variables are plotted, as these were the most severe disturbances. Appendix H has the additional plots for the 2007 Winter peak conditions and Appendix I has a similar set of plots for the 2011 Summer peak conditions.

Table 2-3: Results of Simulations Representing the GEN-2006-022 Plant Without an SVC

FAULT	Summer Peak 2011	Winter Peak 2007
FLT_1_3PH	STABLE	STABLE
FLT_2_1PH	STABLE	STABLE
FLT_3_3PH	STABLE	STABLE
FLT_4_1PH	STABLE	STABLE
FLT_5_3PH	STABLE	STABLE
FLT_6_1PH	STABLE	STABLE
FLT_7_3PH	STABLE	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
FLT_19_3PH	NOT ACCEPTABLE	NOT ACCEPTABLE
FLT_20_1PH	NOT ACCEPTABLE	NOT ACCEPTABLE
FLT_21_1PH	STABLE	STABLE
FLT_22_1PH	STABLE	STABLE

The results of the simulations representing the GEN-2006-022 plant with no SVC indicate that the system response for FLT_19_3PH, and FLT_20_1PH would not be acceptable for either the 2011 Summer Peak condition or for the 2007 Winter Peak condition. These faults involve the loss of the GEN-2006-021 – Harper 138 kV line. This outage forces all of the GEN-2006-021 power to Medicine Lodge, an area that is more highly stressed after the addition of the GEN-2006-022 plant. Following these faults, the voltages at GEN-2006-021 begin oscillating wildly between 0.01 and 2.5 pu, which is an indication of instability. Voltages at GEN-2006-022 oscillate wildly as well between 0.01 and 1.9 pu.

Modeling this same contingency in power flow resulted in a blown up solution. QV analysis of this unsolvable power flow contingency showed a 46 Mvar deficit at the GEN-2006-022 substation 34.5 kV bus, as shown in Figure 2.3-1 below. The height of the QV curve above the horizontal axis represents the minimum Mvar injection necessary to get a power flow solution. As shown in section 2.3.2, even more than this is required to maintain transient stability and keep the wind turbines on line.

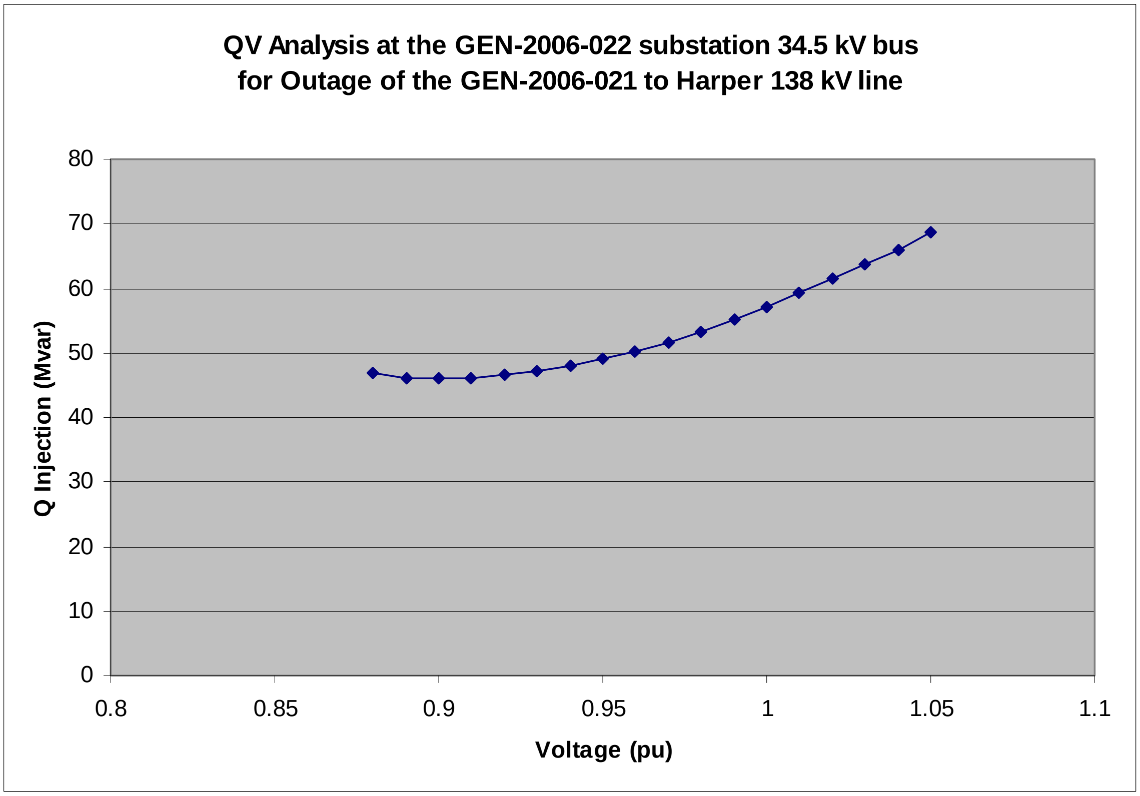


Figure 2.3-1 QV Analysis of Worst Contingency

When the simulations of fault 19 and 20 were run to 10 sec, one or both of the wind farms (GEN-2006-021 and GEN-2006-022) are tripped offline by their high or low voltage relays. The wind turbine speeds continue to rise as well. These two wind farms use Clipper wind turbines that are of the full converter design. The turbines drive synchronous generators whose power is converted completely from AC to DC and then back to AC, thus allowing wind turbine speed to be independent of power system frequency. The continuously rising turbine speed is an indication of the inability of the AC-DC-AC converters to transport the power from the turbines to the power system.

Note that these PSS/E simulations may not be accurate after the first few seconds because wild swings in voltages, especially very high voltages, can excite other effects (e.g. saturation, arrester operation, insulation failure) that are not captured by programs such as PSS/E. Also, it is not known how accurate the Clipper turbine PSS/E models are during unstable conditions. However, it is clear that the results of faults 19 and 20 are not acceptable.

For the other disturbances, the simulated responses are acceptable, no wind farm generation trips, and the system is stable. The plots in Appendix C show that for all of the stable disturbances the GEN-2006-022 voltage is at an essentially constant level after two simulation seconds and that the voltage is far from the trip characteristics of the wind turbines. For all of the stable simulations the power output from the wind turbines has also returned to the pre-disturbance level so the speed is constant and there is no danger of tripping on overspeed or underspeed. The plots in Appendices H and I for simulations FLT_1_3 and FLT_2_1 are extended to 10 seconds to further demonstrate that after two simulation seconds there is no significant movement.

2.3.2 Simulations With An SVC Added at GEN-2006-022

The wind farm was simulated with a (-25 to +75 MVAR) static var compensator (SVC) attached at the low side of the wind farm's 115/34.5 kV transformer. This compensation was included along with the 17 MVAR fixed shunt compensation required to maintain 1.05 per unit pre-disturbance voltage on the wind farms 115 kV bus. The simulation results with the SVC are summarized in Table 2-4. Appendix D has plots showing the time-varying response of key variables for each simulated fault.

Table 2-4: Results for Stability Analysis with a SVC

FAULT	Summer Peak 2011	Winter Peak 2007
FLT_1_3PH	STABLE	STABLE
FLT_2_1PH	STABLE	STABLE
FLT_3_3PH	STABLE	STABLE
FLT_4_1PH	STABLE	STABLE
FLT_5_3PH	STABLE	STABLE
FLT_6_1PH	STABLE	STABLE
FLT_7_3PH	STABLE	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
FLT_19_3PH	STABLE	STABLE
FLT_20_1PH	STABLE	STABLE
FLT_21_1PH	STABLE	STABLE
FLT_22_1PH	STABLE	STABLE

Appendix E has plots for a wider range of variables for FLT_1_3PH with the 2011 Summer Peak loading. Appendix F has plots for a wider range of variables for FLT_19_3PH with the 2011 Summer Peak loading.

With the added SVC rated for -25 to +75 MVAR the simulated system response is acceptable, the GEN-2006-022 generators do not trip, and the SPP system is stable for all the specified faults, for both Summer Peak and Winter Peak conditions**.**

The GEN-2006-022 plant was also tested with a smaller, –25 to +50 MVAR, SVC. Appendix G has these plotted simulation results for FLT-19-3. With the smaller SVC the system response for this fault is not acceptable because the GEN-2006-022 generator trips off line.

3 CONCLUSIONS

The objective of this study is to evaluate the power system stability with the GEN-2006-022 wind farm. The study is performed for the 2007 Winter Peak and the 2011 Summer Peak conditions.

For both conditions, adding enough shunt capacitors to bring the POI power factor to 1.0 would increase the 115 kV voltage above 1.05 pu, which is not acceptable. The recommended level of shunt capacitors is reduced to 17 Mvar to prevent the 115 kV bus voltage from going above 1.05 pu.

With only fixed or mechanically switched shunt compensation the system response is not acceptable for the 2011 Summer Peak condition or for the 2007 Winter Peak condition for the following faults:

- FLT_19_3PH (a three phase fault with unsuccessful re-closing, resulting in the loss of the Harper – GEN-2006-021 138 kV line)
- FLT_20_1PH (a single phase fault with unsuccessful re-closing, resulting in the loss of the Harper – GEN-2006-021 138 kV line)

The response is acceptable for the other faults simulated; GEN-2006-022 would remain on-line, and the SPP system will be stable for both the 2011 Summer Peak and the 2007 Winter Peak system conditions.

The GEN-2006-022 plant was also simulated with a SVC with a –25 MVAR to +75 MVAR range connected to the wind farm 34.5 kV collector system. With this SVC included the wind farm generation does not trip for any of the simulated faults and the system is stable.

The proposed GEN-2006-022 project would not adversely impact the stability of the SPP system if an SVC with at least a –25 MVAR to +75 MVAR range is connected to its 34.5 kV collector bus along with the 17 MVAR shunt capacitors mentioned above. But, simulations with a smaller SVC (-25 to +50 MVAR) indicate that the system response would not be acceptable for some of the simulated faults.

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 - SUMMARY PLOTS FOR ALL FAULT SIMULATIONS REPRESENTING THE GEN-2006-022 PLANT WITHOUT A SVC

APPENDIX D - SUMMARY PLOTS FOR ALL FAULT SIMULATIONS REPRESENTING THE GEN-2006-022 PLANT WITH A –25 TO +75 MVAR SVC

APPENDIX E - 2011 SUMMER PEAK PLOTS FOR FLT_1_3PH WITH A (–25 TO +75 MVAR) SVC

APPENDIX F - 2011 SUMMER PEAK PLOTS FOR FLT_19_3PH WITH A (–25 TO +75 MVAR) SVC

APPENDIX G - 2007 WINTER PEAK PLOTS FOR FLT_19_3PH WITH A (–25 TO +50 MVAR) SVC

APPENDIX H - 2011 SUMMER PEAK PLOTS FOR FLT_1_3, FLT_19_3PH, FLT_2-1, AND FLT_20-1 WITHOUT A SVC

APPENDIX I - 2007 WINTER PEAK PLOTS FOR FLT_1_3, FLT_19_3PH, FLT_2_1, AND FLT_20-1 WITHOUT A SVC