Southwest Power Pool

Impact Re-study For Generation Interconnection Request GEN-2005-012

SPP Tariff Studies

(#GEN-2005-012)

June 2008

Summary

Pursuant to the tariff and at the request of Southwest Power Pool, the following Impact Study has been performed by Power Technologies International (PTI) to satisfy the Impact Study Agreement executed by the requesting Customer and SPP for Generation Interconnection Request #GEN-2005-012. The request for interconnection was placed with SPP in accordance with SPP's Open Access Transmission Tariff, which covers new generation interconnections on SPP's transmission system.

Reduction of Queue Position
The Customer has requested 400 MW of generation to be interconnected at the Spearville 345kV substation. The Impact Study has shown that no more than 250 MW can be interconnected at the Spearville substation without the addition of transmission upgrades.

Power Factor Requirements
The Vestes V-90 wind turbines requested by the Customer to be studied for this project have a power factor capability between 0.98 lagging (providing reactive power) to 0.96 leading (absorbing reactive power) at the generator terminals. Current SPP practice (per FERC Order #661A) is to conduct a power factor analysis to determine if the studied wind turbine's reactive power capability is sufficient for reliability of the system.

The analysis is conducted using the worst case contingency in the local area, from the following Impact Study known to be the outage of the Spearville – Holcomb 345kV transmission line. A var generator was placed at the wind farm 345kV bus to determine the power factor required at the point of interconnection to hold a voltage schedule of 1.0. The results are below.

Season	Outage	Real Power @ POI	Reactive Power @ POI	Power Factor
2012 summer	Holcomb – Spearville 345kV	247.4 MW	57.3 Mvar	97.3 %

From this analysis it was determined that the wind farm would need to meet the SPP requirements for power factor (+/-95% power factor at the point of interconnection). Since the V90 turbines cannot meet this requirement, the Customer will be required to provide additional capacitor banks to meet the +/-95% power factor requirement.

Interconnection Facilities

Please refer to the Facility Study conducted in November, 2007.

R054-08

Generator Interconnection Impact Study GEN-2005-012 - 400 MW Wind Farm Project in Ford County, Kansas Stability Analysis

Prepared for

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Final Report – Review 2
June 23, 2008

Siemens PTI project number: P/21-113261

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Executive Summary

The purpose of this report is to present the results of the stability analysis performed to evaluate the impact of the proposed interconnection of the GEN-2005-012 wind generation project on the Southwest Power Pool system.

Project GEN-2005-012 will be a 400 MW wind generating facility located in Ford County, Kansas. It will be connected to the existing Spearville 345 kV substation, which is owned by Sunflower Electric Cooperative.

The transient stability analysis was performed using the package provide by SPP. It contains the latest stability database in PSS™E version 30.2.1. It was also included the modeling data for the previously queued projects.

According to the analysis carried out, the following points can be highlighted:

- The outage of Spearville – Holcomb 345 kV Line is the most severe contingency when GEN-2005-012 wind farm is in service. Due to lack of transmission it is necessary to limit the queue position to 250MW to avoid GEN-2005-012 instability.

- The analysis indicates that the GEN-2005-012 wind turbines are not tripped off line by voltage protection in any contingency when the queue position is limited to 250 MW.

- In order to meet SPP power factor requirements at the POI, it is necessary to install 15 Mvar at each collector bus (34.5 kV). Taking into consideration the need for flexible switching, the total amount at each collector bus should be split in separated banks. In this study, it was considered three banks.

- For 2012 voltage violations were identified at some 115 kV substations in the pathway Spearville – Medicine Lodge3, in normal conditions (base case). If the existing voltage control resources cannot provide extra reactive support it will be necessary additional capacitor banks, as indicated:

    - Suncity 34.5 kV: 2 x 3.0 Mvar
    - Medicine Lodge 34.5 kV: 1 x 4.80 Mvar
    - Pratt 34.5 kV: 2 x 4.80 Mvar

- The results also show that, except for the outage of Spearville – Holcomb 345 kV Line, the new facility remains online for all other contingencies, despite overloads and voltage support issues. For the years covered by this study, it could be learned from the results, that the GEN-2005-012 project has shown a proper dynamic behavior and its presence does not cause any adverse impact on the system stability.

Section
1

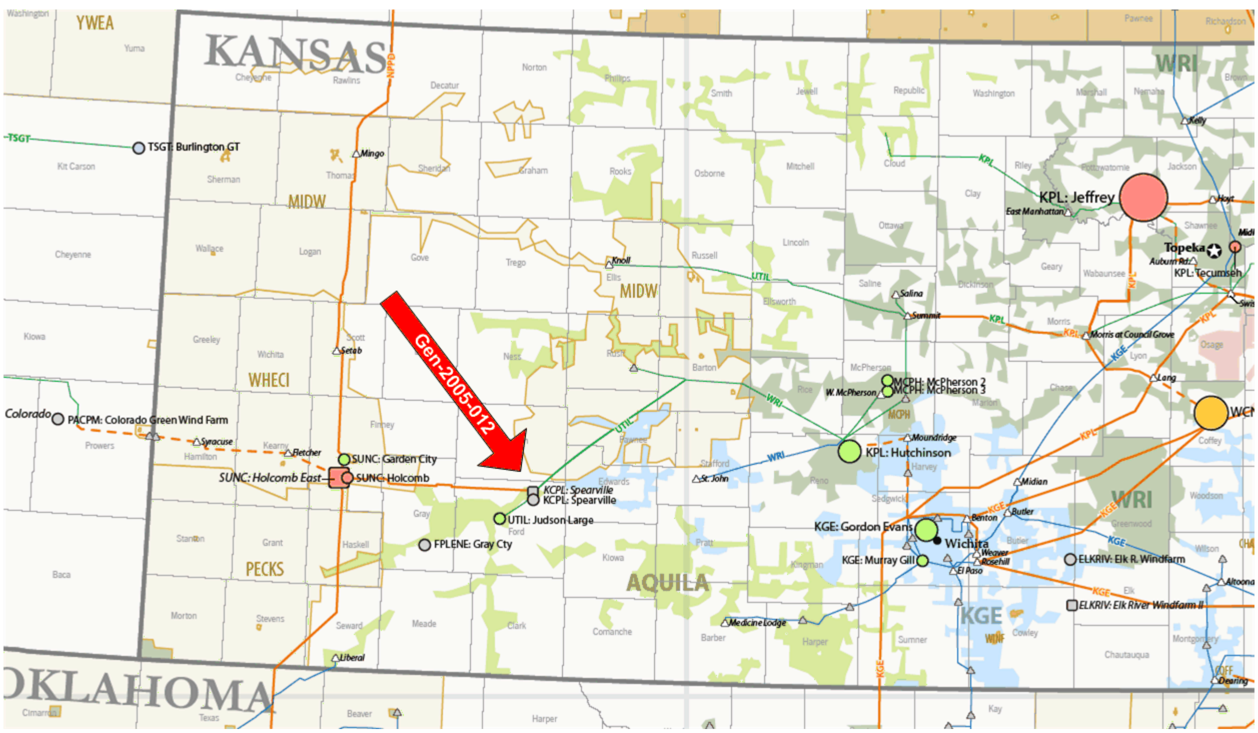
Introduction

1.1 Background

The purpose of this report is to present the results of the stability analysis performed to evaluate the impact of the proposed interconnection of the GEN-2005-012 wind generation project on the Southwest Power Pool system.

Project GEN-2005-012 is a 400 MW wind generating facility located in Ford County, Kansas. It will be connected into the existing Spearville 345 kV substation, which is owned by Sunflower Electric Cooperative. The Figure 1-1 shows the location of the new proposed wind farm.

Figure 1-1: Location of GEN-2005-012



This figure is a part of "Platts U.S. Electric Power System – 2007/2008 Edition". For more information visit www.platts.com

The transient stability analysis was performed using the package provide by SPP. It contains the latest stability database in PSS™E version 30.2.1. It was also included the modeling data for the previously queued projects, as follows:

- Gray County Wind farm – 110 MW.
- GEN-2001-039A – 105 MW.
- GEN-2002-025A – 150 MW.
- GEN-2004-014 – 154.5 MW.

The stability simulations considered both single line to ground and three and phase faults. All single line (SLG) faults have considered delayed clearing as a result of breaker failure. Fourteen contingencies provided by SPP were simulated in this study.

1.2 Purpose

The stability study was carried out to:

(a) Determine the ability of the proposed generation facility to remain in synchronism and within applicable planning standards following system faults with normal and delayed clearing;

(b) Determine the amount of capacitance banks to be added at the wind farm facilities;

(c) Evaluate the maximum generation level of the GEN-2005-012 project in order to avoid stability problems.

Section
2

Model Development

2.1 Power Flow Data

2.1.1 Benchmark Cases (Cases without GEN-2005-012 Project)

The transient stability analysis was performed considering base cases of years 2008 and 2012. Each one with a specific generation dispatch, as follows:

- 2008 – winter peak
- 2012 – summer peak

Figures 2.1 and 2.2 presents the base case considered for years 2008 and 2012. For the area of concern, such figures show power flows and voltages of the 345, 230 and 115 kV systems.

Figure 2-1: Power Flows and Voltages – 2008 without GEN-2005-012

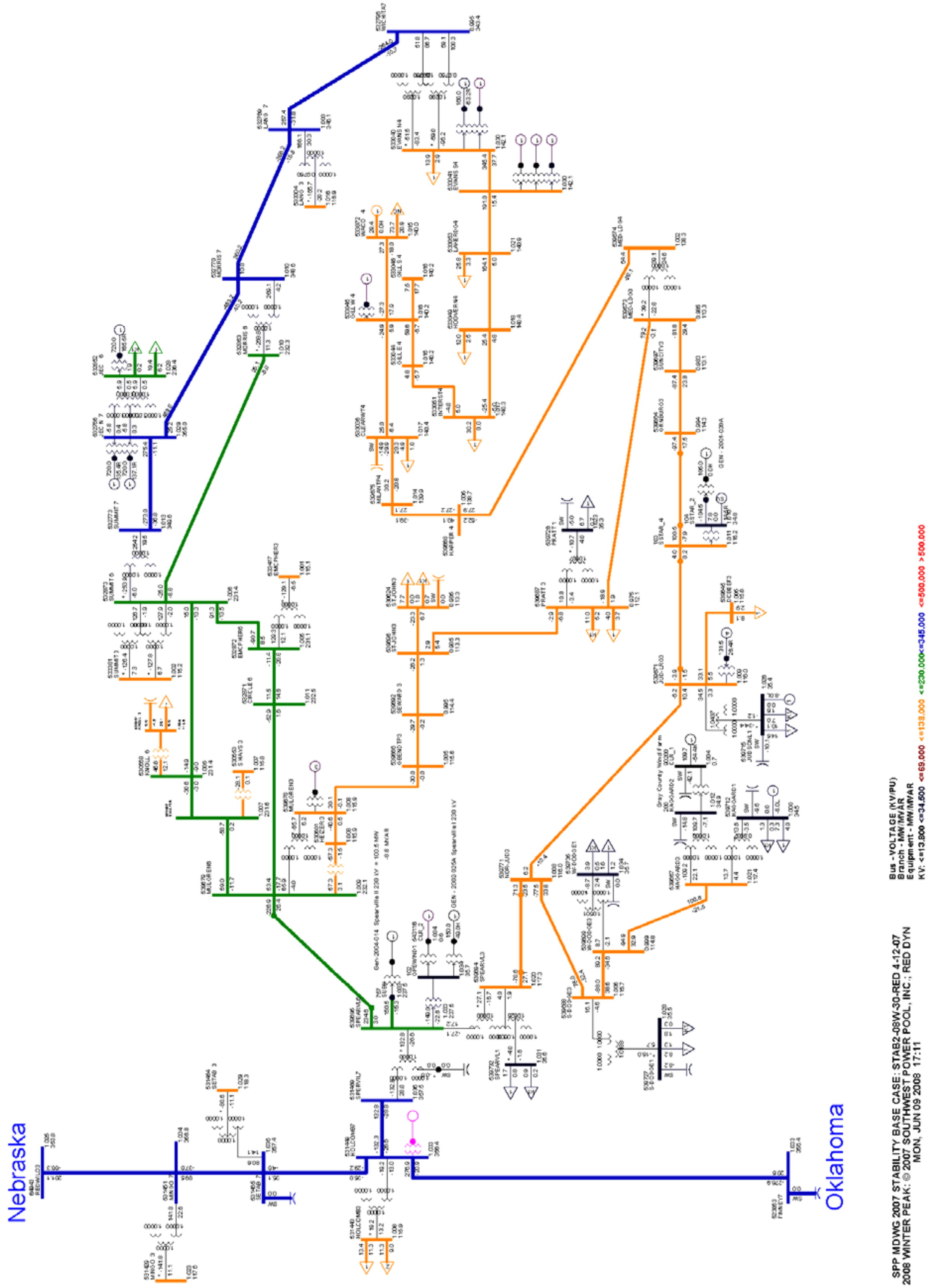
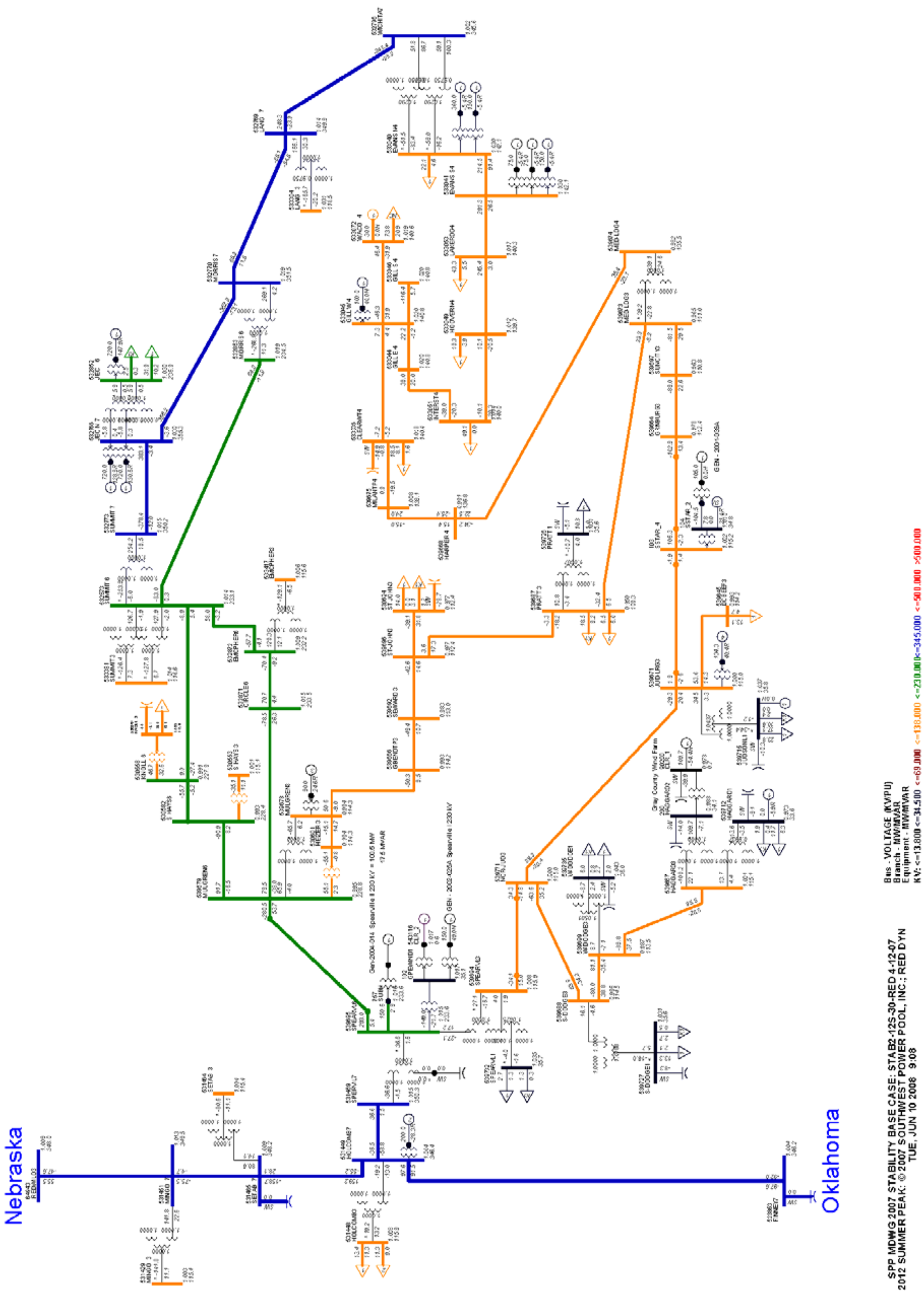


Figure 2-2: Power Flows and Voltages – 2012 without GEN-2005-012



2.1.2 Case with GEN-2005-012 Project

Project GEN-2005-012 was modeled as a 400 MW wind generating facility connected to the Spearville 345 kV substation (existing), in Ford County, Kansas. The detailed data of wind farm collector system was provided by the project developer and is shown in the Appendix A – Base Case Setup.

There are a total of 16 circuits in the collector system, consisting of 5 circuits with 9 turbines each and the remaining circuits with 8 turbines each. The total number of wind turbines is 133.

The collector system is divided in two sets of 8 circuits, each one connected to a 34.5 kV collector bus. The impedances of the cables were provided by the project developer. The collector buses are connected to the POI at 345 kV transmission system through two 345/34.5 kV transformers.

The preliminary load flow analysis has shown that, in order to meet SPP power factor requirements at the interconnection point, it is necessary 15 Mvar in each 34.5 kV collector bus for 250 MW. Taking into consideration the need for flexible switching, total Mvar amount at each bus should be split in separated banks. In this study, it was considered three banks.

The capacitance of collector system cables were also taken into account.

Figures 2.3 and 2.4 present the base case considered for years 2008 and 2012 with the new project in service. For the study area, the following figures show power flows and voltages of the 345, 230 and 115 kV systems.

Figure 2-3: Power Flows and Voltages – 2008, GEN-2005-012 in service

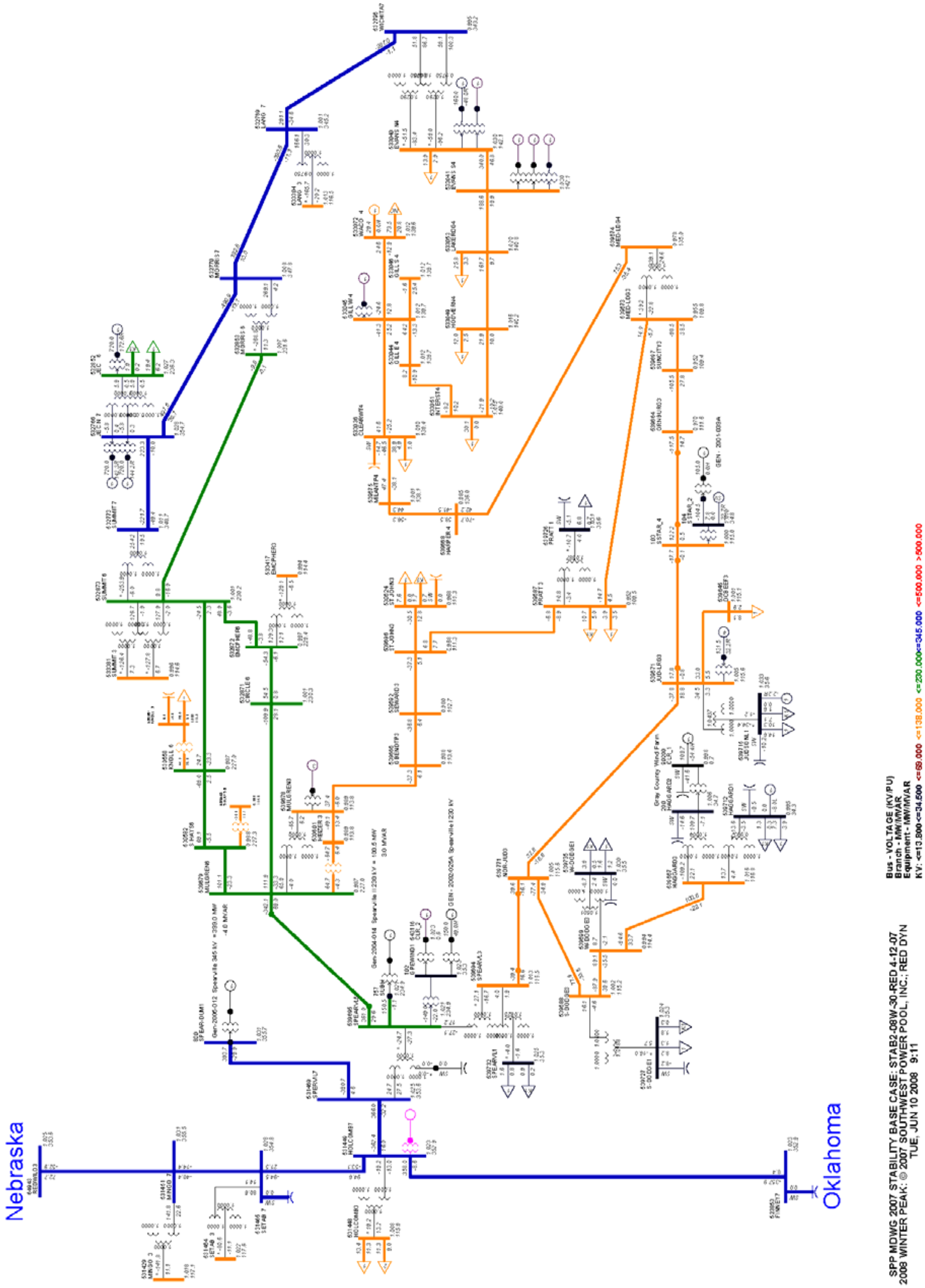
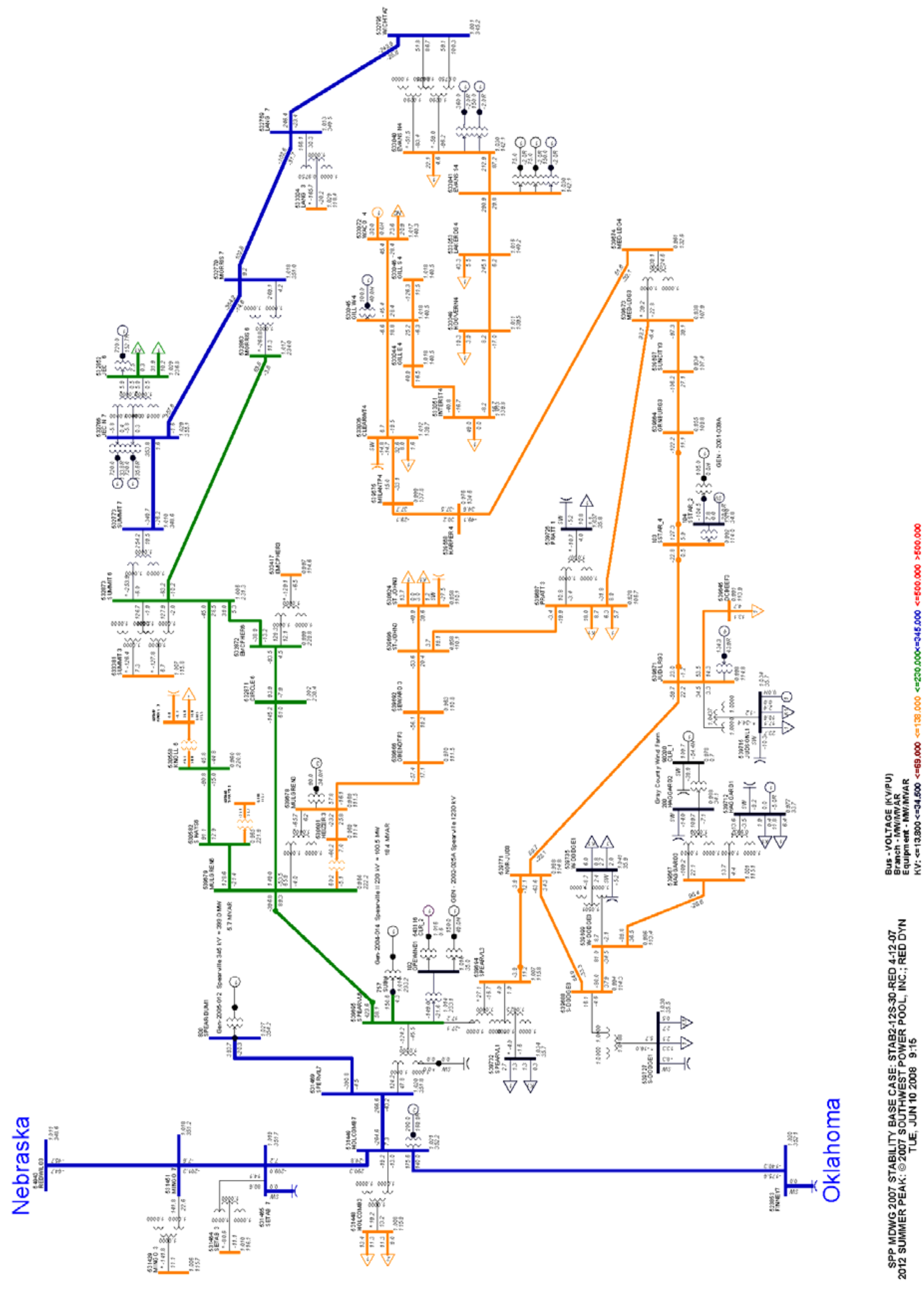


Figure 2-4: Power Flows and Voltages – 2012, GEN-2005-012 in service



2.2 Stability Database

The transient stability analysis was performed using the data provided by SPP. Stability models for the GEN-2005-012 project were added to the dynamic database, based on data documentation given.

2.2.1 GEN-2005-012 Stability Modeling Data

The VESTAS V90 wind turbine model package provided is used in this project to represent the GEN-2005-012 turbines. All turbine parameters used in the simulation models are the default parameters in the wind turbine package. It is assumed that the wind turbine generators (WTGs) would be controlling the voltage of each own bus. The PSS/E data output documenting the model parameters is shown below:

```
PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS/E      WED, APR 23 2008  19:09
 SPP MDWG 2007 STABILITY BASE CASE: STAB2-08W-30-RED 4-12-07
 2008 WINTER PEAK: ¬ 2007 SOUTHWEST POWER POOL, INC.; RED DYN

PLANT MODELS

 REPORT FOR ALL MODELS                     BUS 88011 [WT1-FD1     1.0000] MODELS

** CV90IG **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR         ICON
             88011 WT1-FD1      1.0000 1  35717-35759   16129-16153    1177-1256      263-272

     H         TXHS      TXSG      TXHG      TMVA      RS        RR        XM
   1.0248    0.1005    0.0004    0.0971    3.1600    0.0054    0.0035    3.1740

     XSL    XRL+XRVSC    XRVSC     XGVSC     SLIP0
   0.0648    0.2019    0.0339    0.2262    0.0250

 ** V90PQC **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR         ICON
             88011 WT1-FD1      1.0000 1  114912-114954  45273-45277   21979-21996    6555-6565
               Wind Generator Bus #  88011
               Wind Generator ID       1

    ** TWIND1 ** BUS X-- NAME --X BASEKV MC    C O N S       V A R S        ICONS
             88011 WT1-FD1      1.0000 1  114955-114961  21997-21999    6566-6567

     VWB     T1G      TG     MAXG     T1R     T2R    MAXR
  20.0009999.000   2.500   2.0009999.0009999.000  30.000


 ** TSHAFT for a machine **  BUS X-- NAME --X BASEKV MC    C O N S         STATE          VAR         ICON
                        88011 WT1-FD1      1.0000 1  114962-114966   45279-45280   22000-22002    6568-6570

         D12       K12         Ta1          p         Rq
      0.3545      0.5330      2.6770      2.0000     108.8000


 ** V90AER for DFIG **      BUS X-- NAME --X BASEKV MC    C O N S        STATE          VAR         ICON
                        88011 WT1-FD1      1.0000 1  114967-115006   45281-45281   22003-22012    6571-6573

     VWinit      Lambda_Max      Lambda_Min  PITCH_MAX    PITCH_MIN      GB_Ratio      NLCH5-table
      20.0000       22.0000      0.5000     46.0000      -4.0000     108.8000
               Wind Generator Bus #  88011
               Wind Generator ID       1

 ** V90PCH **  BUS X-- NAME --X BASEKV MC    C O N S     S T A T E S       VAR         ICON
             88011 WT1-FD1      1.0000 1  115007-115154  45282-45290   22013-22063    6574-6577

               Wind Generator Bus #  88011
               Wind Generator ID       1
```

Section

3

Study Assumptions

The previous section of this report describes the base cases development process and the original database additions to include the GEN-2005-012 dynamic models (Vestas V90 wind turbines). The simulation study was carried out using the PSS™E Version 30.2.1.

The study has considered the 2008 and 2012 power flow cases provided by SPP. The base case contains all the significant proposed generation projects ahead in the interconnection queue:

- Gray County Wind farm – 110 MW, consisting of 167 Vestas V47 turbines.
- GEN-2001-039A – 105 MW, consisting of Clipper wind turbines.
- GEN-2002-025A – 150 MW, consisting of 100 GE turbines.
- GEN-2004-014 – 154.5 MW, consisting of 203 GE turbines.

The areas of interest for this study are shown in Table 3-1:

Table 3-1 – Areas of Interest

Area Number	Area Name
526	SPS
531	MIDW
534	SUNC
536	WERE
539	WEPL
541	KACP

3.1 Disturbances for Stability Analysis

The stability simulations included three-phase (3PH) faults and single line-to-ground (SLG) faults. For each single line faults it was also considered a delayed clearing as a result of breaker failure. The disturbances studied are listed in Table 3-2, as follows:

Table 3-2: Disturbances for Stability Analysis

#	Fault Location	Fault Type	Clearing	Fault Clearing
1	At Spearville end of 345 kV line to Holcomb	3PH	Normal	5 cycles - trip Spearville – Holcomb 345 kV
2	At Spearville end of 345 kV line to Holcomb	SLG	Normal	5 cycles - trip Spearville – Holcomb 345 kV 20 cycles – reclosing tripped 345 kV line
3	At Holcomb end of 345 kV line to Finney	3PH	Normal	5 cycles - trip Holcomb – Finney 345 kV
4	At Spearville end of 345 /230 kV Autotransformer	3PH	Normal	5 cycles – trip Spearville 345/230 kV Autotransformer
5	At Mullergren end of 230 kV line to Spearville	3PH	Normal	5 cycles - trip Mullergren – Spearville 230 kV
6	At Mullergren end of 230 kV line to Spearville	SLG	Breaker Failure	7 cycles – trip Spearville end breaker 16 cycles – trip Mullergren – Circle6 230 kV
7	At Spearville end of 230 kV line to Mullergren	3PH	Normal	5 cycles - trip Spearville end breaker 7 cycles – trip Mullergren end breaker
8	At Spearville end of 230 kV line to Mullergren	SLG	Breaker Failure	5 cycles – trip Spearville end breaker 16 cycles – trip Mullergren – Circle6 230 kV
9	At North Judson Large end of 115 kV line to Spearville	3PH	Normal	7 cycles – trip North Judson end breaker 9 cycles – trip Spearville end breaker
10	At North Judson Large end of 115 kV line to Spearville	SLG	Breaker Failure	9 cycles – trip Spearville end breaker 20 cycles – trip North Judson – Judson large 115 kV 20 cycles – trip Haggard – W-Dodge3 115 kV
11	At North Judson Large end of 115 kV line to GEN-2001-039A	3PH	Normal	7 cycles – trip Judson Large end breaker 9 cycles – trip SStar_4 end breaker
12	At North Judson Large end of 115 kV line to GEN-2001-039A	SLG	Breaker Failure	9 cycles – trip SStar_4 end breaker 20 cycles – trip Judson large – North Judson 115 kV 20 cycles – trip Judson large – DCBeef 115 kV 20 cycles – trip CIM-PLT3 – CMRIVTP3 115 kV 20 cycles – trip E-Liber3 – CMRIVTP3 115 kV 30 cycles – trip generator at Judson large
13	At GEN-2001-039A end of 115 kV line to Greenburg	3PH	Normal	7 cycles – trip SStar_4 end breaker 9 cycles – trip Greenburg end breaker
14	At GEN-2001-039A end of 115 kV line to Greenburg	SLG	Breaker Failure	7 cycles – trip SStar_4 end breaker 20 cycles – trip MED-LDG3 – Suncity3 115 kV

In order to simulate the single line to ground faults, it was considered the following equivalent reactors:

Table 3-3: Equivalent Reactors – Line to Ground Faults

Substation / kV	*Equivalent Reactors (MVA)*	
	2008	***2012***
Spearville 345 kV	1,400	1,750
Spearville 230 kV	1,000	1,300
Mullergren 230 kV	1,000	1,200
North Judson 115 kV	770	790
Judson Large	760	780
S Star (GEN-2001-39A)	430	440

In this analysis different thermal limits were considered for most of the lines, since two scenarios are being analyzed: summer and winter peak. Especially for Spearville – Mullergren 230 kV line, it is important highlighting the thermal limits considered:

- 2008 (winter peak)
  - Rate A: 453.3 MVA
  - Rate B: 470.5 MVA
- 2012 (summer peak)
  - Rate A: 330.3 MVA
  - Rate B: 355.3 MVA

With the GEN-2005-012 wind farm in service, its generation leads to an increase in the 230 kV Spearville – Mullergren line, which reaches 127% loading (Rate A), considering the 2012 summer peak thermal limit. Since this analysis does not take into consideration system reinforcements, this line loading will not be considered as a constraint for GEN-2005-012 in order to better investigate the effect of the entire generation amount in the system stability.

On the other hand, it is important to address the issue of Spearville – Mullergren thermal limit, thus avoiding generation constraints for the new facility (in normal conditions).

In addition, the Table 3-4 presents the identified overloads in both 2008 and 2012 cases, without GEN 2005-012 project. It is worth noting that, during contingencies, these line loadings can reach 200 % (Rate B). This is a serious constraint and should be better investigated under planning point of view. Once again, it will not be considered as a limitation for the new wind farm generation, since it is an existing issue.

Table 3-4: Line Overloads - Case Without GEN-2005-012 Wind Farm

Transmission Line	*Line Loading (% - Rate A)*	
	2008	***2012***
S_Star 4 – Greenburg 115 kV	125	133
Sun City – Medicine Lodge 3 115 kV	111	113
Medicine Lodge 4 – Harper 4	84	60

Section

4

Stability Analysis

The objective of this analysis is to determine the impact of the GEN-2005-012 on the system stability performance and to verify the ability of the proposed generation facility to remain in synchronism following system faults with normal and back-up clearing.

Based on the available data, the dynamic analysis of the new facility was carried out and the following results can be drawn:

4.1 Steady State Performance

Comparing the 2008 cases with and without GEN-2005-012 windfarm it is clear that the entire power generated by the new project flows towards Nebraska and Oklahoma direction. As a consequence of the wind farm project, there is an inversion in the power flow through Spearville 345/230 kV autotransformer: 25 MW going into 230 kV system. It also causes an increase in the 230 kV Spearville – Mullergren flow, which reaches 78% loading (Rate A). The voltage profile is reduced by approximately 1%. In Mullegren and South Hays substations the reduction is 2%. That means it is possible to maintain the desirable voltages with the existing voltage control resources.

In 2012 cases it was found the same situation but, due to the fact that the Holcomb generator is in service and its dispatch is 200 MW, there is an increase in the power flow through Spearville 345/230 kV autotransformer, which reaches 125 MW going into 230 kV system. Thus, the loading in the 230 kV Spearville – Mullergren line reaches 127% loading (Rate A), considering the summer peak thermal limit. As exposed in Section 3, it was not considered a constraint for the GEN-2005-012 generation.

For the 345 and 230 systems the voltage profile impact is negligible, except for Mullergren and South Hays 230 kV substations which suffer 3% reduction due to the flow increase. Due to the same reason, it was also identified a voltage profile reduction in the 115 kV pathway Spearville – North Judson – Judson Large – S Star – Greenburg – Suncity – Medicine Lodge for the cases with GEN-2005-012 wind farm.

For 2012 there are voltage violations at the 115 kV substations Suncity, Medicine Lodge and Pratt 3, in normal conditions (base case). The lack of reactive power can be estimated as approximately 20 Mvar. If the existing voltage control resources cannot provide such reactive support, it will be necessary additional capacitor banks. The following amounts/locations are given as a suggestion:

- Suncity 34.5 kV: 2 x 3.0 Mvar
- Medicine Lodge 34.5 kV: 1 x 4.80 Mvar
- Pratt 34.5 kV: 2 x 4.80 Mvar

4.2 Dynamic Results

This sub-section describes the system dynamic behavior under the fourteen contingencies listed in the Table 3-2. Every contingency was evaluated for 2008 and 2012 years and a more detailed description is given for the most severe disturbances.

The plots of selected system variables in the monitored area for each contingency, for both years, are included in Appendix B.

For the outages considered in the monitored area the system presents the following performance:

4.2.1 Loss of Spearville – Holcomb 345 kV line

- *Three phase fault*

  This is the most severe contingency for the system. This outage represents loss of connection with the 345 kV system, which is the main pathway for the power generated by GEN2005-012 wind farm. Since the 230 kV system associated to Spearville does not have enough capability to transmit the entire power from GEN-2005-012, voltage collapse occurs and, as a consequence, the wind turbines lose synchronism.

  The problem is not related only to lack of reactive support. Further, the results indicate strong need for transmission reinforcements in the system associated to Spearville substation.

  Without reinforcements, it is necessary lower the queue position to 250MW, in order to maintain the synchronism. In addition, the loading of the Spearville – Mullergren must be taken into account to avoid post contingency overloads in this line.

- *Single-line-to-ground with reclosing*

  It was found the same behavior of the three phase fault. The reclosing happens after 20 cycles, but at that time the turbines of GEN-2005-012 wind farm have already lost synchronism due to lack of transmission / reactive support.

4.2.2 Loss of 345/230 kV Spearville autotransformer

This outage is not severe. The interrupted flow in 2008 is negligible and, for 2012 this outage means a relief for the Spearville 230 kV system, since it interrupts 125 MW going into 230 kV system. It was not identified any voltage violation.

4.2.3 Loss of Spearville – Mullergren 230 kV line (Cont. # 5, 6, 7 and 8)

These outages are severe from the voltage profile point of view. During each of these contingencies there is a power flow increase in both 115kV pathways: Spearville – Medicine Lodge3 and Mullergren – St. John, in order to keep the supply of Pratt's and St. John's loads. As a consequence, it occurs an accentuate reduction in the voltages at 115 kV substations Suncity, Medicine Lodge and Pratt 3, which present about 5 % of deviation.

Under these outages, the overloads shown in Table 3-4 are accentuated and could reach about 200% (Rate B). The problem happens for both years, but for 2012 it gets worse due both to the new Mullergren generator (90 MW) and GEN-2005-012 wind farm.

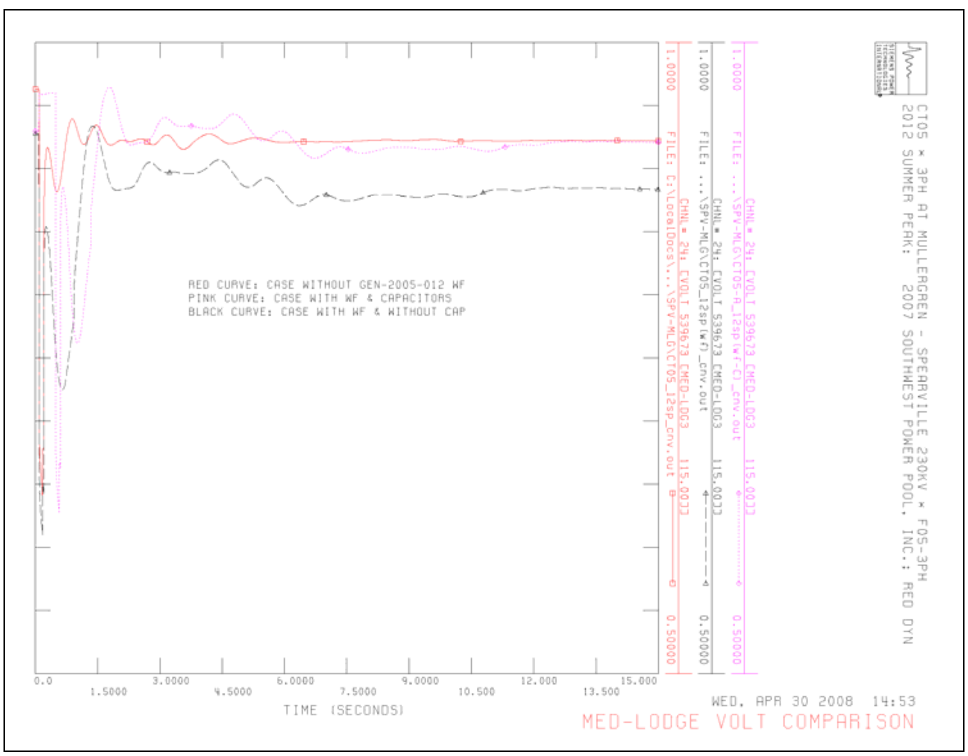
It is important noting that this particular area of the 115 kV system already has a serious line loading and voltage support issue, no matter if GEN-2005-012 is in service or not.

The amount of capacitor banks indicated in subsection 4.1 is expected to compensate the adverse effect of GEN-2005-012 wind farm in 2012, but they are not a solution for the area issue. The optimal solution for the area should address transmission reinforcements.

Figure 4-1 shows voltage comparison for the 115 kV substation Medicine Lodge3 under the same contingency: fault at Mullergren end of 230 kV line to Spearville (F05-3PH). The comparison is made among three different conditions, as follows:

- o Without GEN-2005-012 wind farm
- o With GEN-2005-012 wind farm, without additional reactive support
- o With GEN-2005-012 wind farm, with additional capacitor banks (subsection 4.1)

Figure 4-1 – Voltage Comparison – Contingency F05-3PH



4.2.4 Other Contingencies

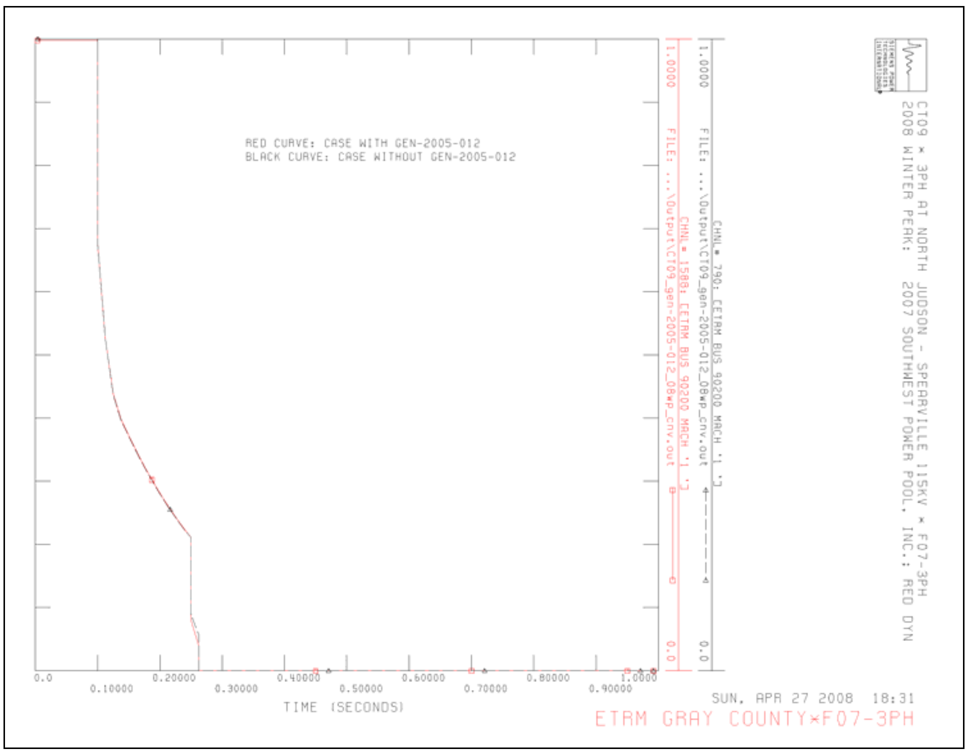
From the dynamic analysis' point of view, the other contingencies are not severe. Under each one of them the system remains in synchronism, with proper damping and within applicable standards.

In general, for all contingencies it was identified that the DC line 43 either blocks or loses order control during fault duration time, but it regains control as soon as the fault is cleared.

On the other hand it is worth noting that, for both years, the Gray County wind farm was tripped off line due to an under voltage relay actuation during several contingencies. The same issue was identified on cases without GEN-2005-012 project, which indicates that the new project has no relation with Gray County's low voltage ride through capability issue.

The Figure 4-2 shows the E terminal of the Gray County wind farm during contingency F07-3PH (North Judson large – Spearville 115 kV). Cleary the wind farm trip happens without influence of GEN-2005-012 project.

Figure 4-2 – Gray County E Terminal – Contingency F07-3PH



The Tables 4-1 and 4-2 summarizes the stability analysis results of the contingency simulations for years 2008 and 2012.

Table 4-1: Stability Analysis Results – 2008

#	*Contingency*	*Results*		
		Without Wind Farm	*With Wind Farm at 250MW*	*With Wind Farm at 400MW*
1	FLT13PH	**Stable** Spearville I and II and Gray County wind farms remain in service	**Stable** Spearville I and II wind farms in service Voltages Ok	**Unstable** GEN-2005-012 loses synchronism voltage collapse in Spearville 230 kV
2	FLT21PH	**Stable** Spearville I and II and Gray County wind farms remain in service	**Stable** Spearville I and II and G. Cty wind farms in service Voltages Ok	**Unstable** GEN-2005-012 loses synchronism voltage collapse in Spearville 230 kV
3	FLT33PH	**Stable** Voltage 345 kV Ok good dynamic behavior	**Stable** Voltage Finney 345 kV Ok good dynamic behavior	**Stable** Voltage Finney 345 kV Ok good dynamic behavior
4	FLT43PH	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
5	F05-3PH	**Stable** Low voltages at Greenburg – Med Lod 115 kV(≈ 0.94 pu)	**Stable** Voltage at Mullergren Ok Low voltage at Greenburg – Med Lod 115 kV (≈ 0.92 pu)	**Stable** Voltage at Mullergren ok Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.90 pu)
6	F05-SLG	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.94 pu)	**Stable** Low voltages at Mullergren (≈ 0.94 pu) and Greenburg – Med Lodge (≈ 0.9 pu)	**Stable** Low voltages at Mullergren 230 kV(≈ 0.92 pu) and Greenburg – Med Lodge 115 kV (≈ 0.9 pu)
7	F06-3PH	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.94 pu)	**Stable** Low voltages Greenburg – Med Lodge 115 kV (≈ 0.93 pu)	**Stable** Voltage at Mullergren ok Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.92 pu)
8	F06-SLG	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.94 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.9 pu)	**Stable** Low voltages at Mullergren 230 kV(≈ 0.92 pu) and Greenburg – Med Lodge 115 kV (≈ 0.9 pu)
9	F07-3PH	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior
10	F07-SLG	**Stable** No voltage violations good dynamic behavior GEN 2001-039A tripped	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior GEN 2001-039A tripped
11	F08-3PH	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior
12	F08-SLG	**Stable** High voltages at Haggard 230 kV(≈ 1.09 pu), North Jud 115 (1.070 pu) and Spearville 115 kV (≈ 1.057 pu)	**Stable** High voltages at Haggard 230 kV(≈ 1.85 pu), North Jud 115 (1.065 pu) and Spearville 115 kV (≈ 1.055 pu)	**Stable** High voltages at Haggard 230 kV(≈ 1.07 pu), North Jud 115 (1.06 pu) and Spearville 115 kV OK
13	F09-3PH	**Stable** No voltages violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
14	F09-SLG	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior	**Stable** No voltage violations good dynamic behavior

Table 4-2: Stability Analysis Results – 2012

#	Contingency	Results		
		Without Wind Farm	*With Wind Farm at 250MW*	*With Wind Farm at 400MW*
1	FLT13PH	**Stable** Spearville I and II and Gray County wind farms remain in service	**Stable** Spearville I and II wind farms remain in service Voltages Ok	**Unstable** GEN-2005-012 loses synchronism voltage collapse in Spearville 230 kV
2	FLT21PH	**Stable** Spearville II 230 kV and Gray Count remain in service	**Stable** Spearville I and II and G. Cty wind farms in service Voltages Ok	**Unstable** GEN-2005-012 loses synchronism voltage collapse in Spearville 230 kV
3	FLT33PH	**Stable** Low voltages at Finney 345 kV(≈ 0.91 pu) good dynamic behavior	**Stable** Low voltages at Finney 345 kV(≈ 0.91 pu) good dynamic behavior	**Stable** Low voltages at Finney 345 kV (≈ 0.90 pu) good dynamic behavior
4	FLT43PH	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
5	F05-3PH	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.92 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.9 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.9 pu)
6	F05-SLG	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.93 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.9 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.9pu)
7	F06-3PH	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.94 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.94 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.91pu)
8	F06-SLG	**Stable** Low voltages at Greenburg M Lodge 115 kV (≈ 0.93 pu)	**Stable** Low voltages at Greenburg – M Lodge 115 kV (≈ 0.91 pu)	**Stable** Low voltages at Greenburg – Med Lodge 115 kV (≈ 0.91 pu)
9	F07-3PH	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
10	F07-SLG	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
11	F08-3PH	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
12	F08-SLG	**Stable** Voltages at Haggard 230 kV N. Jud and Spv 115 kV Ok	**Stable** Voltages at Haggard 230 kV, N. Jud and Spv 115 kV Ok	**Stable** Voltages at Haggard 230 kV, North Judson and Spearville 115 kV Ok
13	F09-3PH	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior
14	F09-SLG	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior	**Stable** No voltages violations good dynamic behavior

Except for the contingencies 1 and 2 (at 400 MW), the GEN-2005-012 wind turbines remain online and stable under the tested contingencies.

Section

5

Conclusion

The proposed GEN-2005-012 - 400 MW wind farm plant has been evaluated to determine the stability impact on the monitored systems. The most important conclusions are given as follows:

- The outage of Spearville – Holcomb 345 kV line is the most severe contingency when GEN-2005-012 wind farm is in service. Due to lack of transmission it causes voltage collapse and, as a consequence, the wind turbines lose synchronism. Since an additional reactive support alone will not solve the problem it was necessary lower the queue position to 250MW.

- The analysis indicates that the GEN-2005-012 wind turbines are not tripped off line by voltage protection in any contingency when the queue position is limited to 250 MW.

- For 2012 voltage violations were identified at some 115 kV substations in the pathway Spearville – Medicine Lodge3, in normal conditions (base case). If the existing voltage control resources cannot provide extra reactive support, it will be necessary additional capacitor banks, as indicated in sub-section 4.1

- It is worth noting that amount of capacitor banks indicated is expected to compensate the adverse effect of GEN-2005-012 wind farm in the 115kV voltage profile for 2012, but they are not a solution for the area issue. The optimal solution for the area should consider, among others, transmission reinforcements, not considered in this analysis.

- Some post-contingency voltage and line loading violations are observed in the same 115 kV pathway. It is important noting that this particular area of the 115 kV system has already problems related to line loadings and voltage support, even if GEN-2005-012 is out of service

- The results also show that, except for contingencies no.1 and 2, the new facility remains online for all other contingencies, despite voltage support issues. For the years covered by this study, it could be learned from the results, that the GEN-2005-012 project has shown a proper dynamic behavior and its presence does not cause any adverse impact on the system stability.