Southwest Power Pool

Impact Study for Generation Interconnection Request GEN–2007–053

SPP Tariff Studies
(#GEN-2007-053)

October, 2009

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-2007-053. 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.

SPP has determined that the interconnection request must be limited to 110MW due to the lack of voltage stability margin at the point of interconnection. The customer will be required to maintain 99% lagging power factor (providing vars) at the point of interconnection.

Disclaimer – This study does not convey any transmission service availability. Although GEN-2007-053 will be permitted to interconnect at 110MW at the requested point of interconnection, there will be NO available transmission service assuming that all prior queued projects are in service due to thermal overloads beyond the point of interconnection (See Feasibility Study for GEN-2007-053 as part of FCS-2008-001 posted December 2008). Any transmission service must be requested through the Southwest Power Pool OASIS.

Interconnection Facility

The primary objective of this study is to identify the system problems associated with connecting the generating plant to the area transmission system. The Feasibility and other subsequent Interconnection Studies are designed to identify attachment facilities, Network Upgrades and other Direct Assignment Facilities needed to accept power into the grid at the interconnection receipt point.

The requirement to interconnect the 150 MW of wind generation into the proposed substation consists of adding a new 161 kV line terminal and breaker at a previously proposed ring-bus switching station. This new station was originally proposed for GI Requests #GEN-2006-014, #GEN-2006-017, #GEN-2007-017 and will be constructed and maintained by MIPU. The Customer did not propose a specific route for the 161 kV line extending to serve its 161/34.5 kV collection facilities. It is assumed that obtaining all necessary right-of-way for the new transmission line to serve its facilities will not be a significant expense.

Power Factor Analysis

ABB conducted a power factor analysis for the project. ABB determined that a 30 Mvar deficiency existed at the point of interconnection. ABB did not optimize the capacitor sizing with the MVar capability of the Customer proposed Gamesa wind turbines. SPP conducted a summary of the power factor requirements below. For the analysis, all wind farms requesting to interconnect at the proposed substation were modeled and the *marginal* power factor (power factor for the next incremental MW) was determined.

Season	Outage	MW at POI (of all wind farms)	Mvars at POI (necessary for all wind farms)	Power Factor required
2010 Summer	MIPU Maryville – Wind Farm Substation	816	39	99.9%
2010 Summer	MIPU Midway – Wind Farm Substation	816	102	99.2%
2010 Summer	MEC Clarinda – Wind Farm Substation	816	69	99.6%

This analysis has determined that the wind farm must be able to provide up to 99.2% power factor (providing vars) at the point of interconnection for the worst case contingency. If the Gamesa turbines are able to provide this power factor at the point of interconnection without the turbine voltage reaching critically high levels (> 1.05 pu) then additional capacitor banks may or may not be necessary.

Stability Analysis

Initial stability analysis performed by ABB revealed undamped oscillations in the Customer wind farm wind generators. After further work with the manufacturer (Gamesa), a new user model was provided and the transmission system tested to be stable and the oscillations were well damped.

P-V Analysis

In conducting the stability analysis for GEN-2007-053, heavy thermal loadings were observed on 161kV lines leading from the wind farm substation. These heavy loadings did not appear to affect the angular stability analysis and the LVRT analysis of the wind farm. However concerns over voltage stability issues prompted the need to conduct a voltage stability analysis. SPP conducted the voltage stability analysis. SPP conducted a P-V analysis at the point of interconnection for the outage of the each of the 161kV transmission lines interconnecting to the wind farm substation. For this analysis, a generator was modeled to represent all wind farms at the substation with reactive compensation to hold the voltage at 1.0 pu.

Using the P-V analysis tool available in PSS/E, it was found that the maximum transfer available from the point of interconnection is approximately 900MW to the knee of the P-V curve. The MEC Clarinda substation is the point of voltage collapse. At voltage collapse, the voltage at Clarinda is approximately 0.88 pu. Please see the Figure 1 for the P-V analysis graph of the Wind Farm – Midway 161kV line.

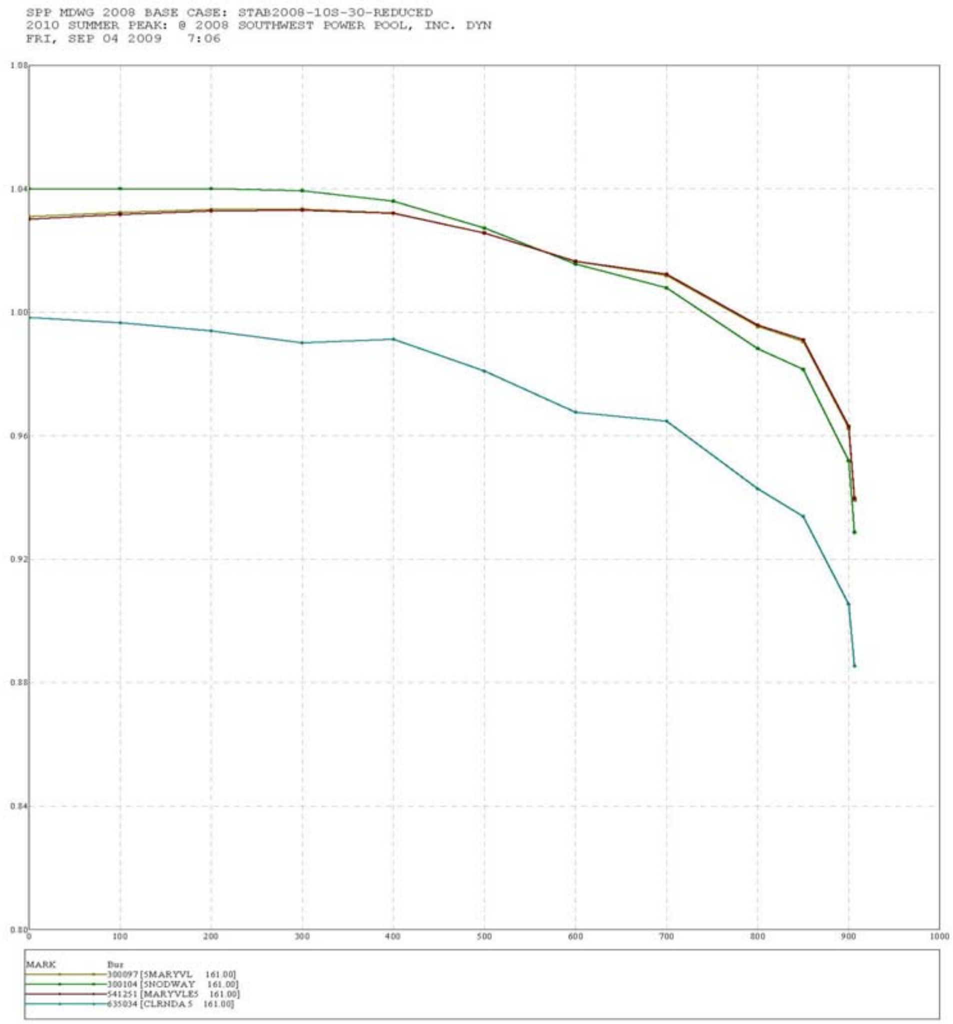

Figure 1. Voltages for Wind Farm Generation for the loss of the Wind Farm – Midway 161kV line

To avoid voltage collapse and by using a 10% safety factor the wind farm generation at the substation should be limited to 810MW. Noting there are 700 MW of prior queued wind farms at this substation, it is the recommendation to lower the queue position of this generation interconnection request to 110 MW. To maintain a 150MW queue position, transmission reinforcements will be required. The Customer may request to have these transmission reinforcements developed during a Facility Study if the Customer chooses to execute a Facilities study agreement.

POWER SYSTEMS DIVISION
GRID SYSTEMS CONSULTING

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2007-053

DRAFT REPORT

REPORT NO.: 2009-E3058-R0
Issued: August 04, 2009

ABB Inc.
Power Systems Division
Grid Systems Consulting
940 Main Campus Drive, Suite 300
Raleigh, NC 27606

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ABB Inc – Grid Systems Consulting

Technical Report

Southwest Power Pool, Inc.	**No.** 2009-E3058-R0	
Impact Study for Generation Interconnection request GEN-2007-053	Date: August 04, 2009	# Pages 37

Author(s):	**Reviewed by:**	**Approved by:**
Kondalarao B	Amit Kekare	Willie Wong

Executive Summary

Southwest Power Pool, Inc. (SPP) has commissioned ABB Inc. to perform a generator interconnection study for a 161 kV interconnection of a 150 MW wind farm in Nodaway County, Missouri. This wind farm will be interconnected into a proposed 161kV substation near the Kansas City Power & Light GMO (KCPL) Maryville substation to be built for GEN-2006-014. The proposed station is to be built for generation interconnection request GEN-2007-053. As per the developer's request, the 150 MW of additional generation was studied using Gamesa 2.0MW wind turbines. Faults were simulated on the SPP system for Winter Peak 2010 and Summer Peak 2010 conditions.

This interconnection of wind farm was studied under two different system loading scenarios - 2010 winter peak and 2010 summer peak. Equivalent generators and collector bus systems were modeled at the proposed new substation (#89572).

The main objectives of this study were

1) To determine the need of reactive power compensation, if any, for the proposed wind farms
2) To determine the impact of proposed GEN-2007-053 generation on system stability and the nearby transmission system and generating stations.
3) To validate the compliance with FERC LVRT requirement for wind farms.

To achieve these objectives the following analyses were performed on the 2010 Summer Peak and 2010 Winter Peak system conditions with GEN-2007-053 in-service

- Power factor analysis for the selected contingencies.
- Transient stability analysis under various local and regional contingencies.
- LVRT performance under selected contingencies near POI.

Following is the summary of study findings:

<u>Power factor analysis</u>

The power factor analysis was performed to determine the need of additional reactive power compensation, if any, for the GEN-2007-053 wind farm projects. The results of power factor analysis indicated that GEN-2007-053 wind farm project would require total of 30 Mvar shunt compensation (e.g. shunt capacitor banks) to meet the power factor requirement at the POI.

It should be noted that during this study the Gamesa 2.0 MW wind turbine generators in GEN-2007-053 wind farm project were assumed to be operated at fixed unity p.f. at machine terminal. The reactive power required to maintain the acceptable voltage and p.f. at the POI was provided by using shunt capacitors at the 34.5 kV collector bus. The WTGs reactive power capability would influence the sizing of the shunt capacitors. Optimization between the WTG reactive power capacity and the shunt capacitors was not performed in this study.

Stability Analysis

The stability analysis was performed to determine the impact, if any, of the proposed GEN-2007-053 project on the stability of the SPP system. The significant results of stability analysis are as follows:

- Undamped oscillations in the speed of GEN-2007-053 (150 MW comprised of Gamesa 2.0 MW WTGs) were observed following all the simulated faults. Further investigation indicated that the undamped oscillations are due to the user-written model used for representing the Gamesa wind turbine generators.
- Sensitivity analysis with an updated user-written model for Gamesa wind turbine was performed. The undamped oscillations in the speed of the equivalent wind generator were not observed.
- The system was found to be STABLE following all the simulated faults with the GEN-2007-053 project.

No stability criteria violations were observed following series of simulated faults at or near the POI after interconnection of the proposed project.

Based on the results of the stability analysis, it is concluded that the proposed wind farm does not adversely impact the stability of the SPP system.

FERC Order 661A Compliance – The proposed project (GEN-2007-053) complies with the latest FERC order on low voltage ride through for wind farms. With this arrangement, these wind farms would not trip off line by voltage relay actuation for local faults near the POI.

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

Rev No.	Revision Description	Date	Authored by	Reviewed by	Approved by
0	Draft Report	08/04/09	Kondalarao B	A. Kekare	W. Wong
DISTRIBUTION: Charles Hendrix – Southwest Power Pool, Inc.					

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1 INTRODUCTION

SPP has commissioned ABB Inc. to perform an interconnection impact study for a 150 MW wind farm in Nodaway County, Missouri. This wind farm will be interconnected into a proposed 161 kV substation near the Kansas City Power & Light GMO (KCPL) Maryville substation to be built for GEN-2006-014. The proposed station is to be built for generation interconnection request GEN-2007-053. The 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 the additional 150 MW wind farm to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios, 2010 Winter Peak and the 2010 Summer Peak. Figure 1-1 shows the location of the proposed 150 MW wind farm interconnecting station and Figure 2-1 shows a one-line of the proposed interconnection with the existing network.

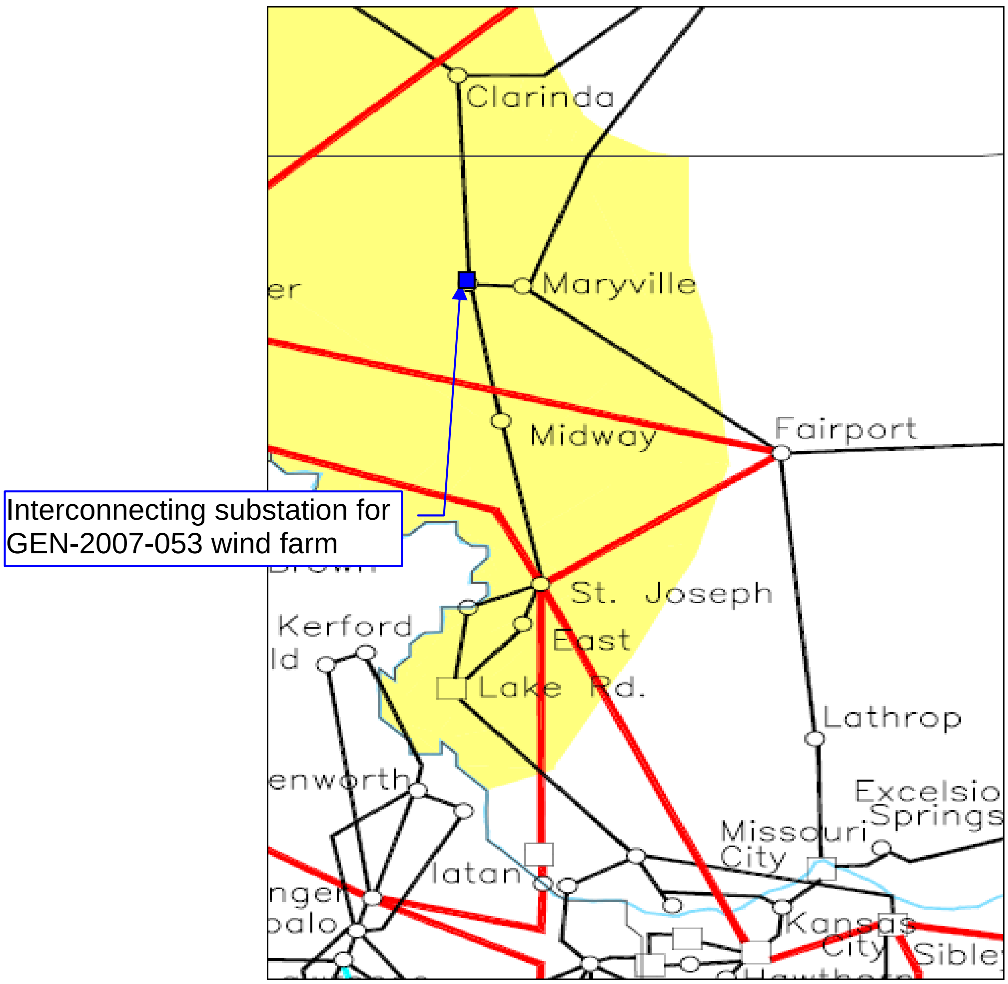

Figure 1-1 GEN-2007-053 interconnecting substation

2 PROJECT DETAILS

The details of load flow and dynamic data for the GEN-07-053 wind farm projects are included in the **Error! Reference source not found.**.

2.1 GEN-2007-053

- Wind farm rating: 150 MW
- Interconnection:

  Voltage: 161 kV

  Location: 161kV substation near the Kansas City Power & Light GMO (KCPL) through 34.5/161 kV transformer

  Transformer: Step-up transformers connecting to the 161 kV

  MVA: 76/126/158 MVA

  Voltage: 161/34.5 kV

  Z: 9.76 % on 76 MVA

- Wind Turbines:

  Number: Seventy Five (75)

  Manufacturer: Gamesa

  Type: Doubly-fed induction generator (DFIG)

  Machine Terminal voltage: 6.9 kV

  Rated Power: 2.0 MW

  Frequency: 60 Hz

  Generator Step-up Transformer

  MVA: 2.35
  High voltage: 34.5 kV,
  Low voltage: 0.69 kV
  Z: 11.6% on 2.35 MVA

- Reactive Power Capability: 0.95 lagging/ 0.95 leading
- PSSE Model Used GXX001_R02_02_v303

Reactive power compensation of 30 MVAR (e.g. shunt capacitor bank) was modeled for the proposed GEN-2007-053 Windfarm to maintain POI power factor near to unity.

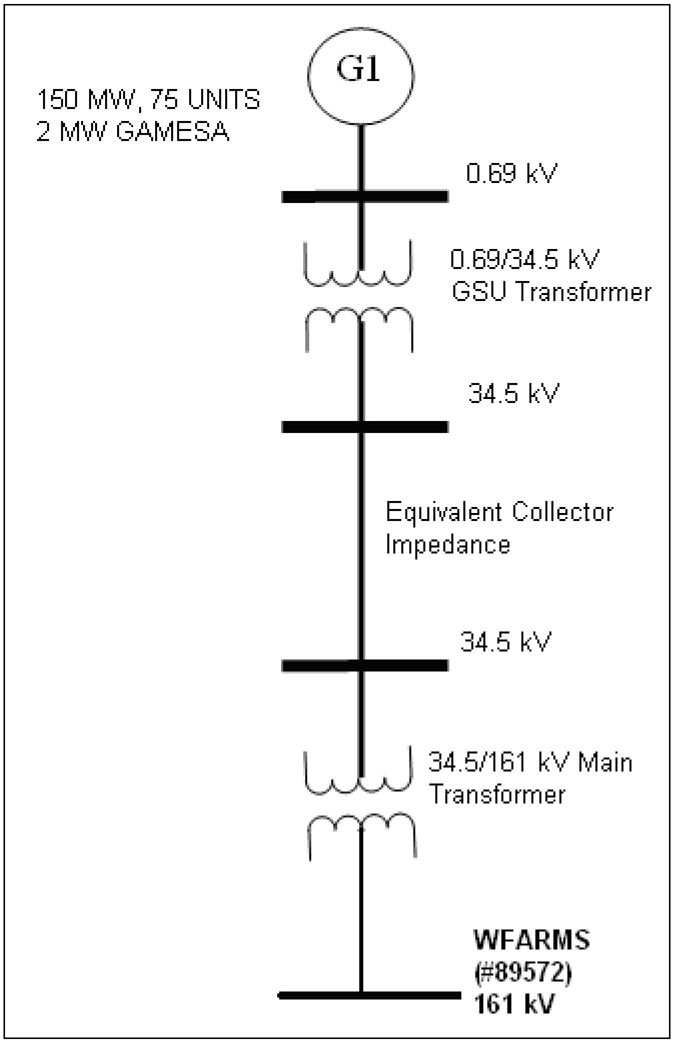

Figure 2-1 GEN-2007-053 Wind Farm One-Line

It should be noted that the Gamesa wind turbine generators are doubly fed induction generators (DFIG) with a reactive power capability of +/- 0.95 p.f. In power factor control mode the Gamesa wind turbine generators operate at a constant power factor. Hence, during this study the wind turbine generators were assumed to be operated at fixed unity p.f. at machine terminal. The reactive power required to maintain the acceptable voltage and p.f. at the POI was provided by using shunt capacitors at the 34.5 kV collector bus. The WTGs reactive power capability would influence the sizing of the shunt capacitors. Optimization between the WTG reactive power capacity and the shunt capacitors was not performed in this study.

3 STUDY METHODOLOGY

3.1 POWER FACTOR ANALYSIS

SPP transmission planning practice[1] requires the generation interconnection projects

a. To maintain the power factor at the Point of Interconnection (POI) to near-unity for system intact conditions and within lag/lead 0.95 p.f. range for post-contingency conditions ,and
b. To maintain the voltage at the POI in 0.95 – 1.05 p.u. range in post-contingency conditions.

If the reactive power capability of the proposed project is not adequate to meet the above-mentioned requirements then additional reactive power compensation (e.g. shunt capacitors) need to be added.

The purpose of the power factor analysis was to determine whether the proposed wind farm projects will meet the power factor requirement at the Point of Interconnection (POI) in system intact and contingency conditions.

Following steps were taken to perform the power factor analysis:

- A VAR generator with large capacity (+/- 9999 Mvar) was modeled at the POI of the subject wind farm. The VAR generator was set to hold the POI voltage consistent with the voltage schedule in the provided base case or 1.00 p.u. (whichever was higher). The reactive power capability of the wind farm was set to zero.
- A list of selected contingencies in the vicinity of the subject windfarm project was simulated. The results were used to identify the most-limiting contingency from steady state voltage and power factor perspective.
- If the required reactive power support, to maintain an acceptable power factor at the POI, was found to be beyond the capability of proposed windfarm then the additional reactive power compensation (e.g. shunt capacitor banks) was considered.

It is important to note that the reactive power compensation identified in this analysis was primarily to meet steady state criteria. The need for dynamic reactive power support, if any, will be determined during transient stability analysis.

3.2 TRANSIENT STABILITY ANALYSIS

The purpose of the transient stability analysis was to determine the “collective impact”, if any, of the wind farm GEN-2007-053 project on the system stability and the nearby transmission system and generating stations.

Using Planning Standards approved by NERC, the following stability definition was applied in the Transient Stability Analysis:

[1] The SPP transmission planning practice was provided for the purpose of this study.

"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."

Stability analysis was performed using Siemens-PTI's PSS/E™ dynamics program V30.3.2. Three-phase and single-line-to-ground (SLG) faults were simulated for the specified duration and synchronous machine rotor angles and wind turbine generator speeds were monitored to check whether synchronism is maintained following fault removal.

For three-phase faults, a fault admittance of –j2E9 was used (essentially infinite admittance or zero impedance). The PSS/E dynamics program only simulates the positive sequence network. Unbalanced faults (like single-phase line faults) involve the positive, negative, and zero sequence networks. For unbalanced faults, the equivalent fault admittance was inserted in the PSS/E positive sequence model between the faulted bus and ground to simulate the effect of the negative and zero sequence networks. For a single-line-to-ground (SLG) fault, the fault admittance equals the inverse of the sum of the positive, negative and zero sequence Thevenin impedances at the faulted bus. Since PSS/E inherently models the positive sequence fault impedance, the sum of the negative and zero sequence Thevenin impedances needs to be added and entered as the fault impedance at the faulted bus. The fault impedance was estimated to give a positive sequence voltage at the fault location of approximately 60% of pre-fault voltage, which is a typical value.

Another important aspect of the stability analysis was to determine the ability of the wind generators to stay connected to the grid during disturbances. This is primarily determined by their low-voltage ride-through capabilities – or lack thereof – as represented in the models by low-voltage trip settings. The Federal Energy Regulatory Commission (FERC) Post-transition period LVRT standard for Interconnection of Wind generating plants includes a Low Voltage Ride Through (LVRT) requirement. The key features of LVRT requirements are:

- A wind generating plant must remain in-service during three-phase faults with normal clearing (maximum 9 cycles) and single-line-to-ground faults with delayed clearing, and have subsequent post-fault recovery to pre-fault voltage unless the clearing of the fault effectively disconnects the generator from the system.
- The maximum clearing time the wind generating plant shall be required to withstand a three-phase fault shall be 9 cycles after which, if the fault remains following the location-specific normal clearing time for three-phase faults, the wind generating plant may disconnect from the transmission system. A wind generating plant shall remain interconnected during such a fault on transmission system for a voltage level as low as zero volts, as measured at the high voltage side of the GSU connected at POI.

These criteria were used to evaluate the LVRT capabilities of the GEN-2007-053 project.

4 STUDY MODEL DEVELOPMENT

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

Pre-Project Power Flow Case

SPP provided two (2) PSS/E power flow cases called "*GEN-2007-053_wp.sav*" representing the 2010 Winter Peak conditions and the "*GEN-2007-053_sp.sav*" representing the 2010 Summer Peak conditions.

This leads to two pre-project cases, named as;

- *GEN-2007-053_wp-PRE.SAV* – a 2010 winter peak case
- *GEN-2007-053_sp-PRE.SAV*– a 2010 summer peak case

The power flows in pre-project conditions are shown in Figure 4-1 and Figure 4-2.

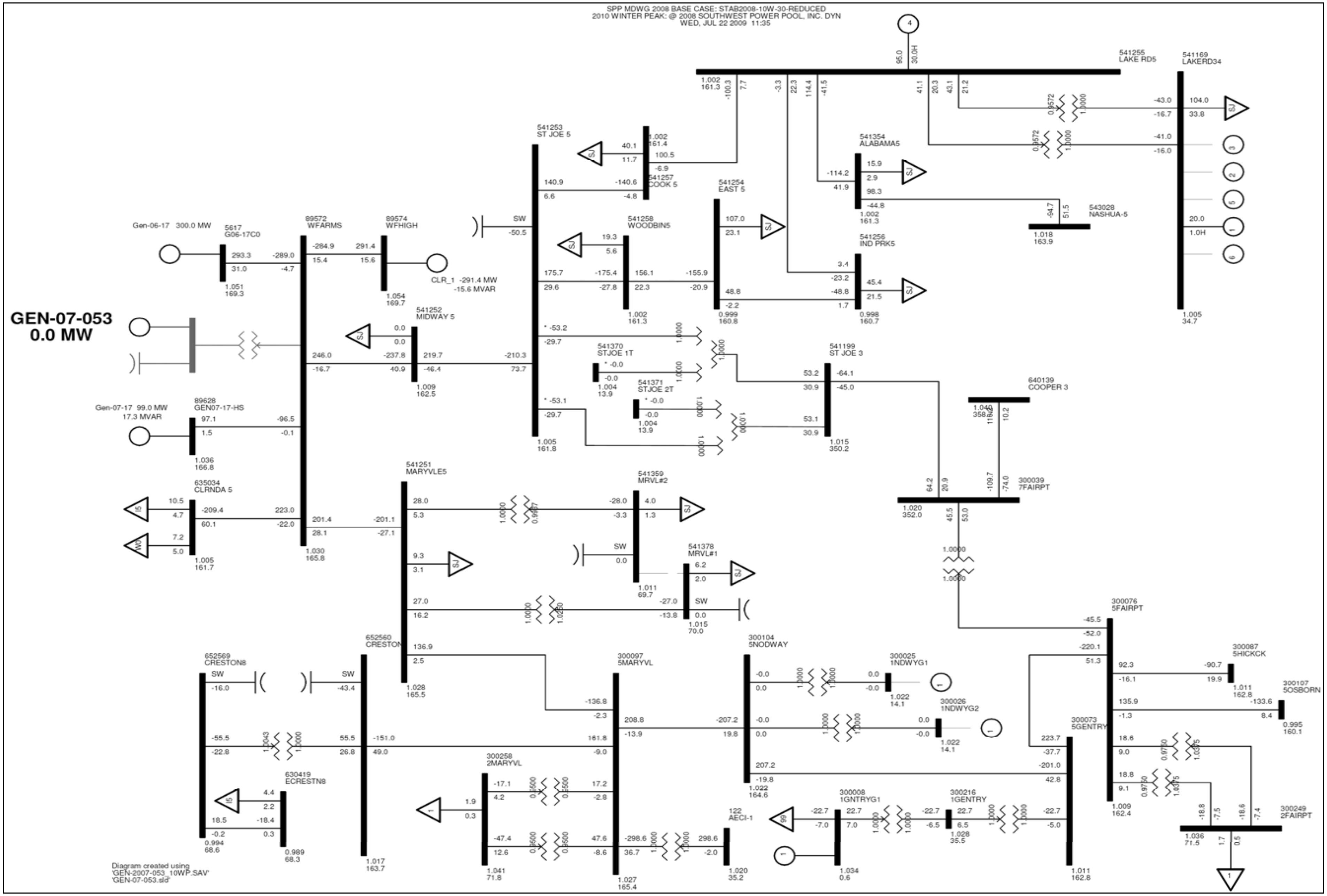

Figure 4-1 2010 Winter Peak case <u>without</u> GEN-2007-053

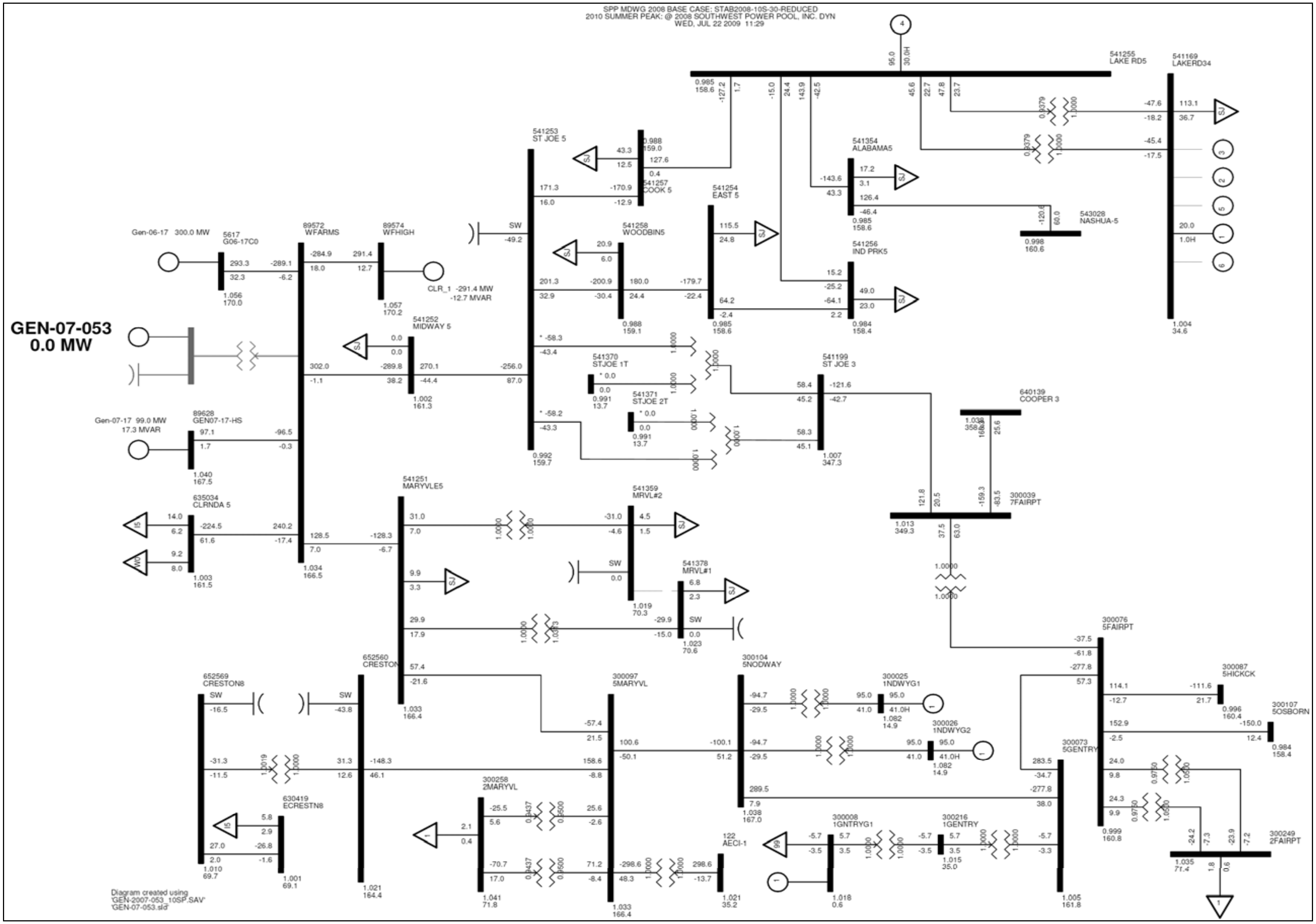

Figure 4-2 2010 Summer Peak case without GEN-2007-053

<u>GEN-2007-053 Wind Farm Power Flow Cases</u>

The GEN-2007-053 wind farm will comprise of total seventy five (75) Gamesa 2.0 MW wind turbine generators. For the stability purpose these seventy five (75) turbines were modeled as five (5) equivalent generators. Five equivalent collector bus systems were modeled representing the entire collector bus system in the proposed windfarm. The equivalent generator was connected to a 34.5 kV collector bus through a five (5) separate equivalent generator step-up transformers (0.69/34.5 kV)

The 34.5 kV collector substation was connected to POI via single 34.5/161 kV station transformer.

A 30 Mvar shunt capacitor bank was modeled at 34.5 kV collector bus to maintain a near-unity p.f. at the POI.

To balance the additional 150 MW of generation, prior-queued and existing generation was scaled down in Subsystem provided by SPP, as shown in **Error! Reference source not found.**. Thus two power flow cases with GEN-2007-053 were established:

- *GEN-2007-053_wp-POST.sav – 2010 winter peak case with GEN-2007-053 using Gamesa 2.0 MW turbine generators*
- *GEN-2007-053_sp-POST.sav – 2010 summer peak case with GEN-2007-053 using Gamesa 2.0 MW turbine generators*

The detailed process of wind farm model development is described in **Error! Reference source not found.**.

Table 4-1 GEN-2007-053 project details

System condition	MW	Location	Point of Interconnection	Sink
2010 Winter Peak	150	Nodaway County, Missouri	Substation near the Kansas City Power & Light GMO (KCPL) 161 kV (#89572)	Generation in SPP footprint
2010Summer Peak	150	Nodaway County, Missouri	Substation near the Kansas City Power & Light GMO (KCPL) 161 kV (#89572)	Generation in SPP footprint

Figure 4-3 and Figure 4-4 show the one-line diagrams for the local area with the wind farm for 2010 Winter Peak and 2010 Summer Peak respectively.

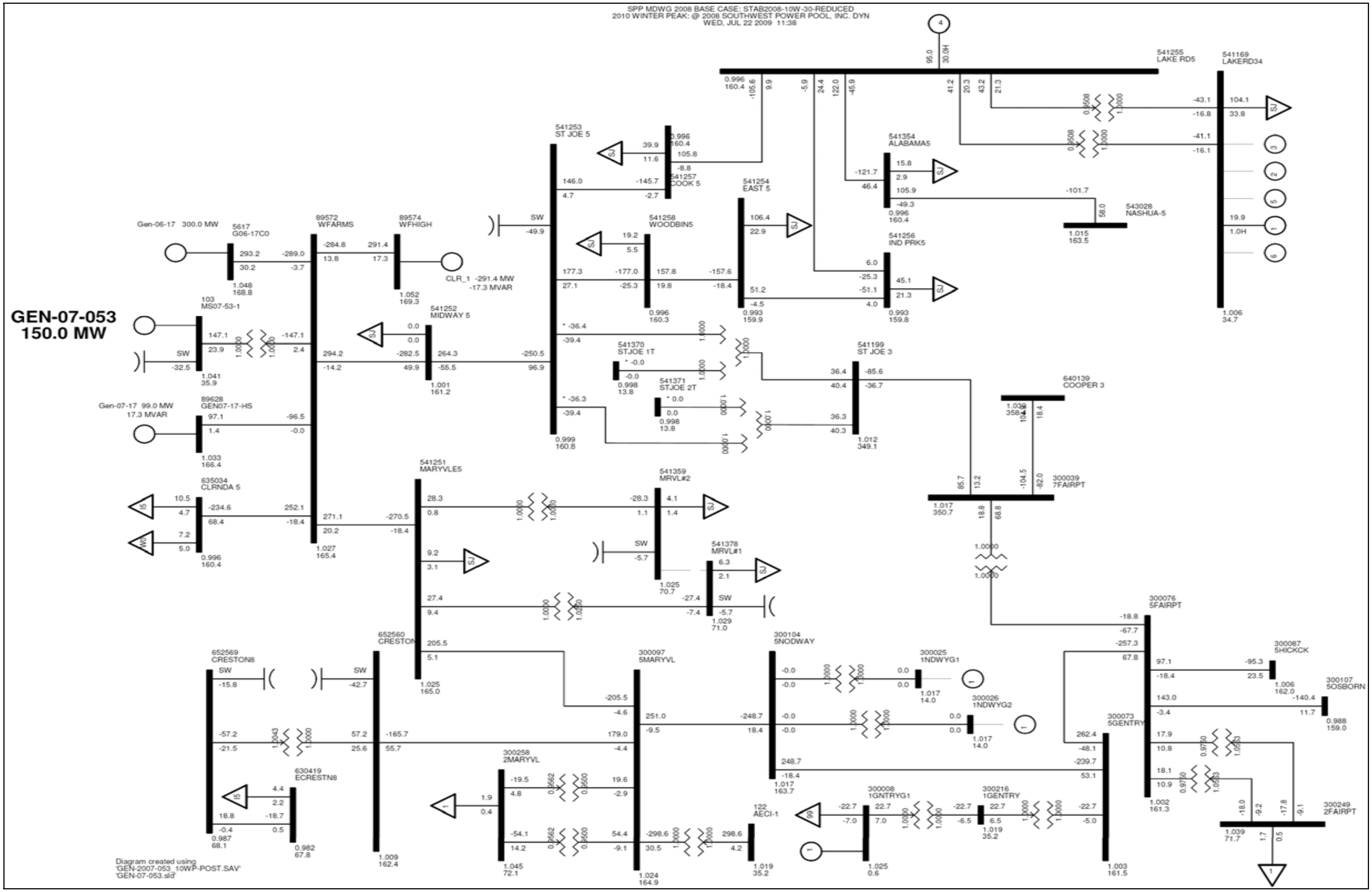

Figure 4-3 2010 Winter Peak case with GEN-2007-053

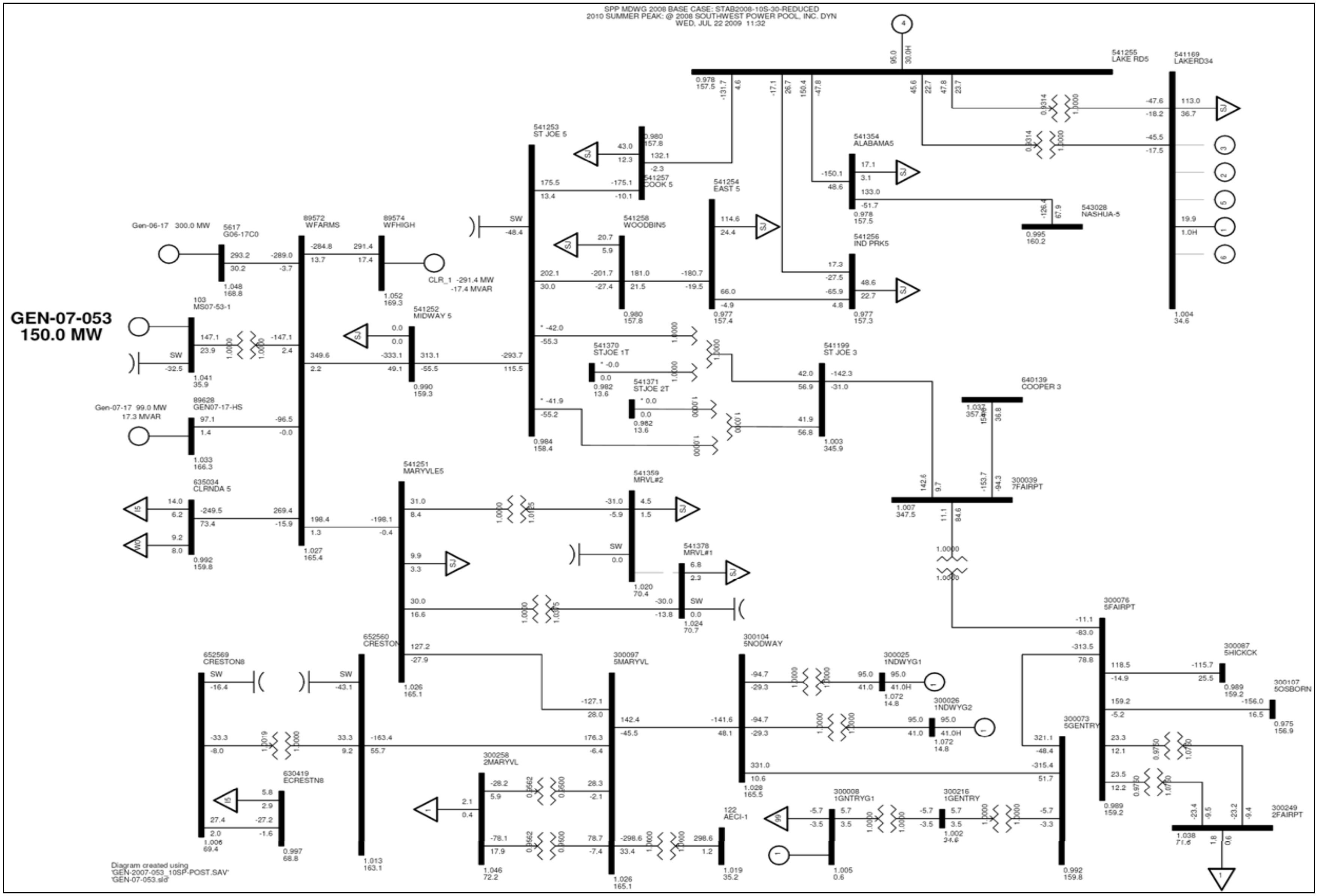

Figure 4-4 2010 Summer Peak case <u>with</u> GEN-2007-053

5 POWER FACTOR ANALYSIS RESULTS

Table 5-1 lists the contingencies simulated for Power Factor analysis.

Table 5-1: List of contingencies simulated for Power Factor Analysis

Cont. Name	Contingency Description
CONT 01	TRIP LINE FROM BUS 89572 TO BUS 541251 CKT1
CONT 02	TRIP LINE FROM BUS 89572 TO BUS 541252 CKT1
CONT 03	TRIP LINE FROM BUS 541251 TO BUS 300097 CKT1
CONT 04	TRIP LINE FROM BUS 635034 TO BUS 89572 CKT1 TRIP LINE FROM BUS 541251 TO BUS 89572 CKT1
CONT 05	TRIP LINE FROM BUS 300097 TO BUS 300104 CKT1
CONT 06	TRIP LINE FROM BUS 300097 TO BUS 652560 CKT1
CONT 07	TRIP LINE FROM BUS 541252 TO BUS 541253 CKT1
CONT 08	TRIP LINE FROM BUS 541199 TO BUS 541253 TO BUS 541370 CKT1 TRIP LINE FROM BUS 541199 TO BUS 541253 TO BUS 541371 CKT2
CONT 09	TRIP LINE FROM BUS 300073 TO BUS 300076 CKT1

5.1 POWER FACTOR ANALYSIS RESULTS FOR GEN-2007-053

The proposed GEN-2007-053 windfarm (150 MW) will be comprised of Gamesa 2.0 MW wind turbine generators. These wind turbine generators are doubly fed induction generators (DFIG) with a reactive power capability of +/- 0.95 p.f. The wind turbine generators were modeled in voltage control mode.

Next, as described in section 3.1, the VAR generator was modeled at POI. The VAR generator was set to hold the 161 kV POI voltage consistent with the pre-contingency voltage schedule in the provided base cases.

The contingencies from Table 5-1 were simulated on 2010 summer peak and 2010 winter peak system conditions. Table 5-2 lists the VARs provided by the VAR generator at POI following the simulated contingencies.

Table 5-2 VAR generator output at the GEN-07-053 POI

Contingency	2010 summer peak	2010 winter peak
SYSTEM INTACT (ALL LINES IN-SERVICE)	0	0
CONT_01	38	29.9
CONT_02	101.5	85.5
CONT_03	47.5	24.7
CONT_05	72.7	61.2
CONT_06	41.7	32.7
CONT_07	97.0	82.2
CONT_08	70.2	51.5
CONT_09	106.7	60.8

The results indicated that the *CONT_02*: loss of WFARMS – MIDWAY 161 kV line and *CONT_09:* loss of GENTRY – FAIRPT 161 kV line will yield maximum reactive power output in winter peak and summer peak system conditions respectively

In addition to the above analysis, the list of contingencies was repeated without the VAR generator at the POI. The voltage at the POI was monitored. The results of the contingency analysis are included in **Error! Reference source not found.**. The *CONT_01:* loss of WFARMS – MARYVLE 161 kV line and *CONT_02*: loss of WFARMS – MIDWAY 161 kV line resulted in lowest voltage at POI in post-contingency conditions in both summer peak and winter peak system condition.

Next, the '*CONT_01*', '*CONT_02*' and '*CONT_09*' were repeated without the VAR generator. The Table 5-3 summarizes the results of the post-contingency voltage and p.f. at the POI. The results indicated that the GEN-2007-053 wind farm has adequate reactive power capability to maintain required p.f. and the voltage at the POI in system intact and in post-contingency conditions for simulated contingencies. Hence, GEN-2007-053 wind farm does not require any additional reactive power support (e.g. shunt capacitor banks etc.).

Table 5-3: Voltage & p.f. at POI without VAR generator: GEN-2007-053 with total 30 Mvar shunt compensation

System condition		Voltage (in p.u.)	P.F.	Additional Mvars from the system at 161 kV POI	Acceptable POI voltage?	Acceptable POI p.f.?
2010 summer peak	System Intact	1.027	0.9998	2.4	YES	YES
	Post-cotingency (1)	0.980	0.9972	10.9	YES	YES
	Post-cotingency (2)	0.989	0.9980	9.3	YES	YES
	Post-cotingency (3)	0.998	0.9986	7.7	YES	YES
2010 winter peak	System Intact	1.027	0.9998	2.4	YES	YES
	Post-cotingency (1)	1.002	0.9989	6.9	YES	YES
	Post-cotingency (2)	1.002	0.9989	6.9	YES	YES

(1)'CONT_01': loss of WFARMS – MARYVLE 161 kV line
(2)'*CONT_02*': loss of WFARMS – MIDWAY 161 kV line
(3)'*CONT_09*': loss of GENTRY – FAIRPT 161 kV line

The results of power factor analysis indicated that total of 30 Mvar shunt compensation will be required to meet the required p.f. and the voltage at the POI in system intact and in post-contingency conditions for simulated contingencies.

It should be noted that the Gamesa wind turbine generators are doubly fed induction generators (DFIG) with a reactive power capability of +/- 0.95 p.f. In power factor control mode the Gamesa wind turbine generators operate at a constant power factor. Hence, during this study the wind turbine generators were assumed to be operated at fixed unity p.f. at machine terminal. The reactive power required to maintain the acceptable voltage and p.f. at the POI was provided by using shunt capacitors at the 34.5 kV collector bus. The WTGs reactive power capability would influence the sizing of the shunt capacitors. Optimization between the WTG reactive power capacity and the shunt capacitors was not performed in this study.

6 STABILITY ANALYSIS RESULTS

Stability simulations were performed to examine the transient behavior of the GEN-2007-053 project and impact of the proposed addition of generation on the SPP system. A number of three-phase and single phase faults with re-closing were simulated.

Stability Database

SPP provided two dynamic databases – *gen-2007-053_wp.dyr* and *gen-2007-053_sp.dyr* – compatible with aforementioned powerflow cases.

A user-written model for the Gamesa 2.0 MW wind turbines for GEN-2007-053 was provided by SPP. The dynamics data for five (5) equivalent generator was appended to the *.dyr files provided by the customer to create respective dynamic databases with the GEN-2007-053 project data. The details of the dynamic model are presented in Appendix B.

Simulated Disturbances

Table 6-1 lists the faults simulated for stability analysis.

Table 6-1 List of Faults for Stability Analysis

Cont. Name	Description
FLT13PH	3 phase fault on the Wind Farm Station (#89572) - Maryville (#541251) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station (#89572). b. Clear fault after 5 cycles by tripping the line from the Wind Farm - Maryville c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT21PH	*Single phase fault and sequence like Cont. No. 1*
FLT33PH	3 phase fault on the Wind Farm (#89572) - Midway (#541252) 161kV line, near the wind farm. a. Apply fault at the Wind Farm. b. Clear fault after 5 cycles by tripping the line from the Wind Farm - Midway c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT41PH	*Single phase fault and sequence like Cont. No.3*
FLT53PH	3 phase fault on the Maryville (#541251) to AECI Maryville (#300097) 161kV line, near Maryville. a. Apply fault at the Maryville. b. Clear fault after 5 cycles by tripping the line from Maryville- AECI Maryville c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT61PH	*Single phase fault and sequence like Cont. No.5*
FLT73PH*	3 phase fault on the Wind Farm (#89572) to Clarinda (#635034) 161kV line, near Wind Farm. a. Apply fault at Wind Farm. b. Clear fault after 5 cycles by tripping the line from Wind Farm -Clarinda

Cont. Name	Description
	c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT81PH	*Single phase fault and sequence like Cont. No.7*
FLT93PH	3 phase fault on the AECI Maryville (#300097) to AECI Nodaway (#3000104) 161kV line, near AECI Maryville. a. Apply fault at the AECI Maryville. b. Clear fault after 5 cycles by tripping the line from AECI Maryville-Nodaway c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT101PH	*Single phase fault and sequence like Cont. No.9*
FLT113PH	3 phase fault on the AECI Maryville (#300097) to Creston (#652560) 161kV line, near AECI Maryville. a. Apply fault at the AECI Maryville. b. Clear fault after 5 cycles by tripping the line from AECI Maryville-Creston c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT121PH	*Single phase fault and sequence like Cont. No.11*
FLT133PH	3 phase fault on the Midway (#541252) – St. Joseph (#541253) 161kV line, near the Midway. a. Apply fault at the Midway. b. Clear fault after 5 cycles by tripping the line from the Midway – St. Joe c. Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT141PH	*Single phase fault and sequence like Cont. No.13*
FLT153PH	3 phase fault on a St. Joe 345/161kV autotransformer a. Apply fault at St. Joe 345kV (#541199). b. Clear fault after 5 cycles by tripping the auto c. no reclose
FLT161PH	*Single phase fault and sequence like Cont. No.15*
FLT173PH	3 phase fault on the Fairport – Gentry wind farm (#300073) 161kV bus at Fairport (#300076) a. Apply fault at Fairport (#300076). b. Clear fault after 5 cycles b tripping the line from Fairport to Gentry c Wait 20 cycles, and then re-close the line in (b) back into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FLT181PH	*Single phase fault and sequence like Cont. No.15*

*Note: Original fault definition Maryville (#541251) to Clarinda (#635034) has changed due to tap in between.

6.1 STUDY RESULTS

All the three phase and single phase faults listed in Table 6-1 were simulated. Responses of the wind generators and other nearby generators were monitored. The system was stable following all the simulated faults. The proposed windfarm and all the windfarms in the local area remained on-line following all the simulated faults.

The results indicated undamped oscillations in the speed of the proposed wind farm following all the simulated faults. Stability results for fault FLT01-3PH summer peak and winter peak results are shown in Figure 6-1 and Figure 6-2. The results of the stability analysis are included in reference **Error! Reference source not found.**.

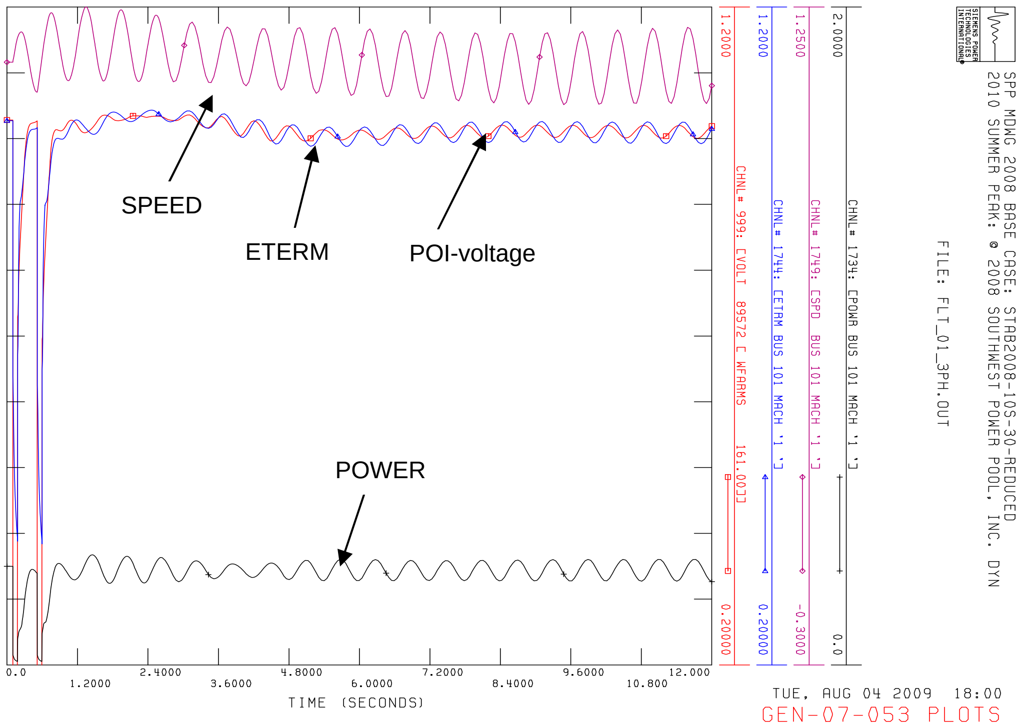

Figure 6-1 GEN-2007-053 response following FLT01-3PH (summer peak)

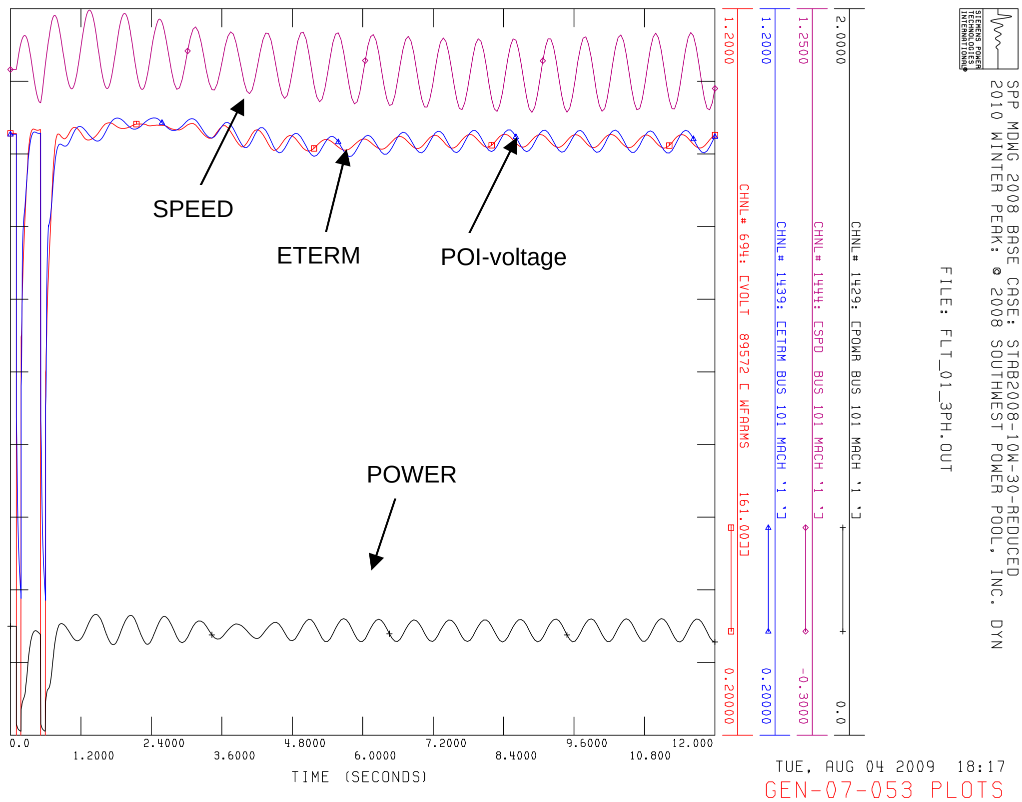

Figure 6-2 GEN-2007-053 response following FLT01-3PH (winter peak)

Further investigation indicated that the undamped oscillations are due to the user-written model used for representing the Gamesa 2.0 MW wind turbine generators. A sensitivity analysis was performed with updated user-written model. The detailed discussion of the sensitivity analysis is included in section 7.

6.2 FERC LVRT COMPLIANCE

Proposed GEN-07-053 windfarm low voltage ride through settings provided with the user written model were used. To determine the compliance of the GEN-07-053 wind farm projects total of six (6) faults were simulated. Faults were simulated at the POI of GEN-07-053 wind farm project and normally cleared by tripping one transmission element at a time. Table 6-2 lists the faults simulated for LVRT analysis.

Table 6-2: List of faults for FERC LVRT compliance

Fault Name	Description
FLT01-3PH_LVRT	3 phase fault on the Wind Farm Station (#89572) - Maryville (#541251) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station 161kV bus. b. Clear fault after 5 cycles by tripping the faulted line.
FLT03-3PH_LVRT	3 phase fault on the Wind Farm Station (#89572) - Midway (541252) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station 161kV bus. b. Clear fault after 5 cycles by tripping the faulted line.
G06-17C0-3PH_LVRT	3 phase fault on the Wind Farm Station (#89572) - G06-17C0 (#5617) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station 161kV bus. b. Clear fault after 5 cycles by tripping the faulted line.
WFHIGH-3PH_LVRT	3 phase fault on the Wind Farm Station (#89572) - WFHIGH (#89574) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station 161kV bus. b. Clear fault after 5 cycles by tripping the faulted line.
GEN07-17-HS -3PH_LVRT	3 phase fault on the Wind Farm Station (#89572) - GEN07-17-HS (#89628) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station 161kV bus. b. Clear fault after 5 cycles by tripping the faulted line.
FLT07-3PH_LVRT	3 phase fault on the Wind Farm Station (#89572) - Clarinda (#635034) 161kV line, near the wind farm. a. Apply fault at the Wind Farm Station 161kV bus. b. Clear fault after 5 cycles by tripping the faulted line.

The results of the simulations indicated that GEN-2007-053 wind farm project meet the FERC LVRT criteria for the interconnection of the windfarm generation (FERC Order 661 – A).

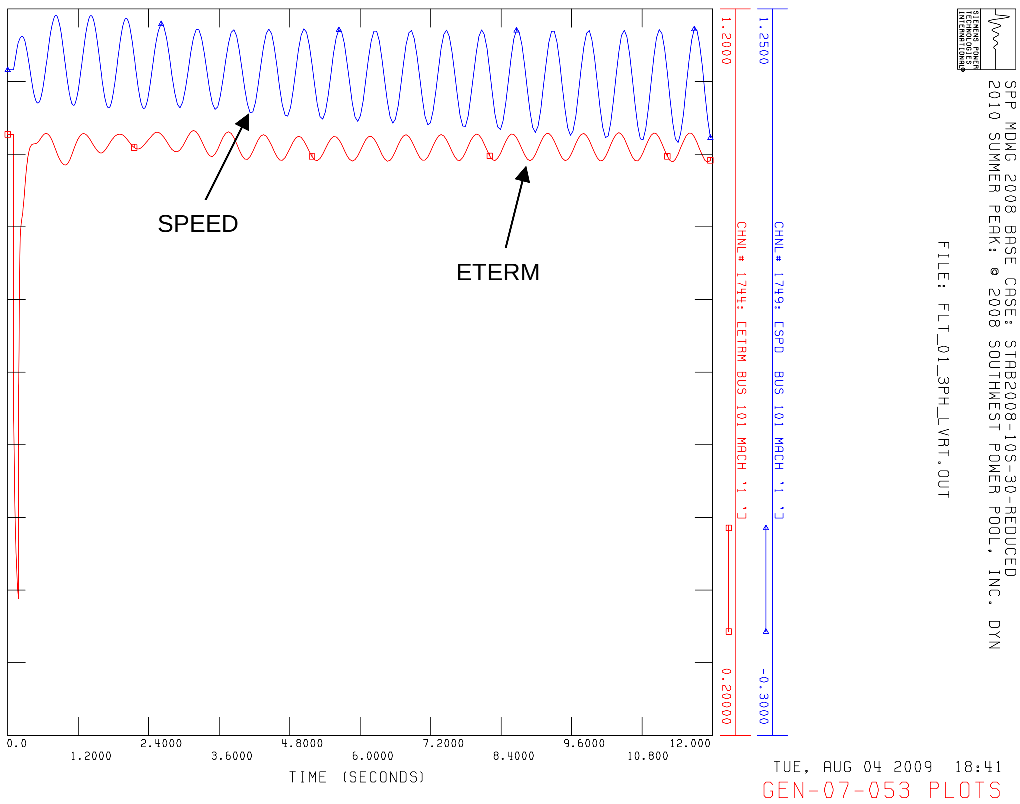

Figure 6-3 Voltage recovery following FLT01-3PH_LVRT (summer peak)

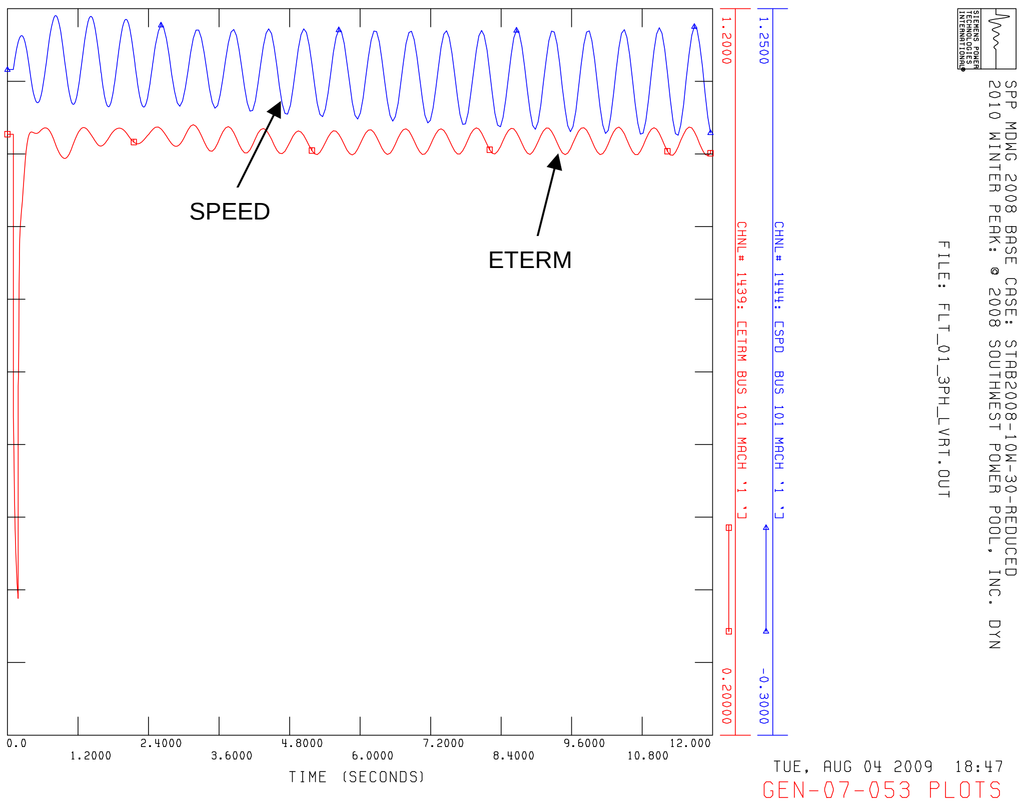

Figure 6-4 Voltage recovery following FLT01-3PH_LVRT (winter peak)

The results of the FERC LVRT compliance are included in **Error! Reference source not found.** for reference

7 SENSITIVITY ANALYSIS

As discussed in section 6.1, a sensitivity analysis was performed with a updated user-written model for Gamesa 2.0 MW wind-turbine generators.

7.1 STUDY RESULTS

All the three phase and single phase faults listed in Table 6-1 were repeated with updated Gamesa 2.0 MW user-written model. Responses of the wind generators and other nearby generators were monitored.

The system was found to be stable following all the simulated faults. No undamped oscillations in the speed of the proposed windfarm generator were observed. Stability results for fault FLT01-3PH summer peak and winter peak results are shown in Figure 7-1 and Figure 7-2.
The results for the simulated disturbances are summarized in Table 7-1.

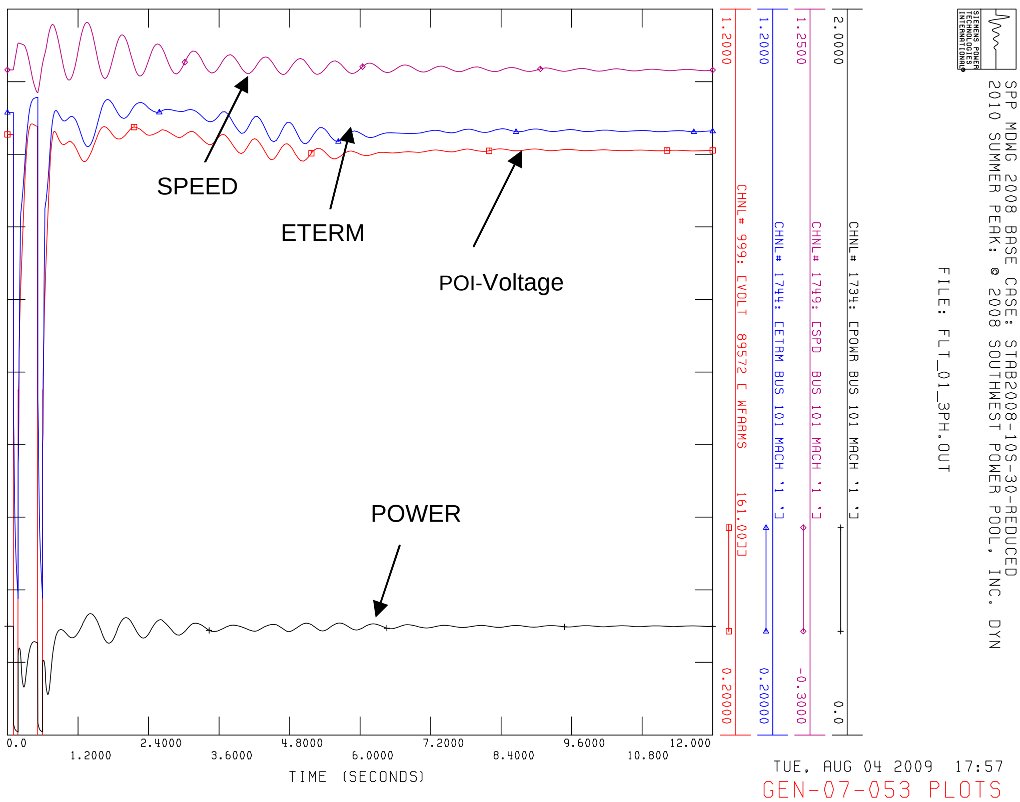

Figure 7-1 GEN-2007-053 response following FLT01-3PH
(summer peak updated model)

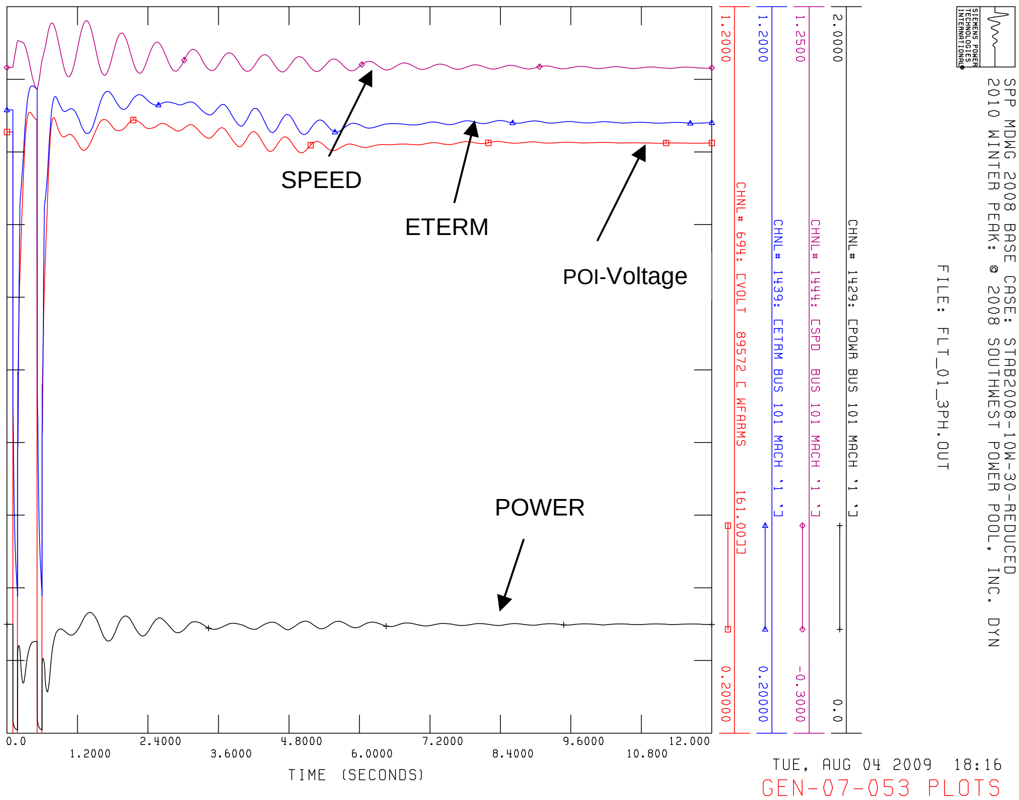

Figure 7-2 GEN-2007-053 response following FLT01-3PH
(winter peak updated model)

Table 7-1 Results of Stability Simulations

	2010 Winter Peak		2010 Summer Peak	
FAULT	**Pre-project**	**Post-project**	**Pre-project**	**Post-project**
FLT_01_3PH	---	STABLE	---	STABLE
FLT_02_1PH	---	STABLE	---	STABLE
FLT_03_3PH	---	STABLE	---	STABLE
FLT_04_1PH	---	STABLE	---	STABLE
FLT_05_3PH	---	STABLE	---	STABLE
FLT_06_1PH	---	STABLE	---	STABLE
FLT_07_3PH	---	STABLE	---	STABLE
FLT_08_1PH	---	STABLE	---	STABLE
FLT_09_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

Hence, GEN-2007-053 project does not have any adverse impact on the system stability in SPP area following simulated disturbances. The results of the stability analysis are included in reference **Error! Reference source not found.**.

7.2 FERC LVRT COMPLIANCE (UPDATED MODEL)

All the three phase faults listed in Table 6-2 were repeated with updated Gamesa 2.0 MW user-written model for LVRT analysis.

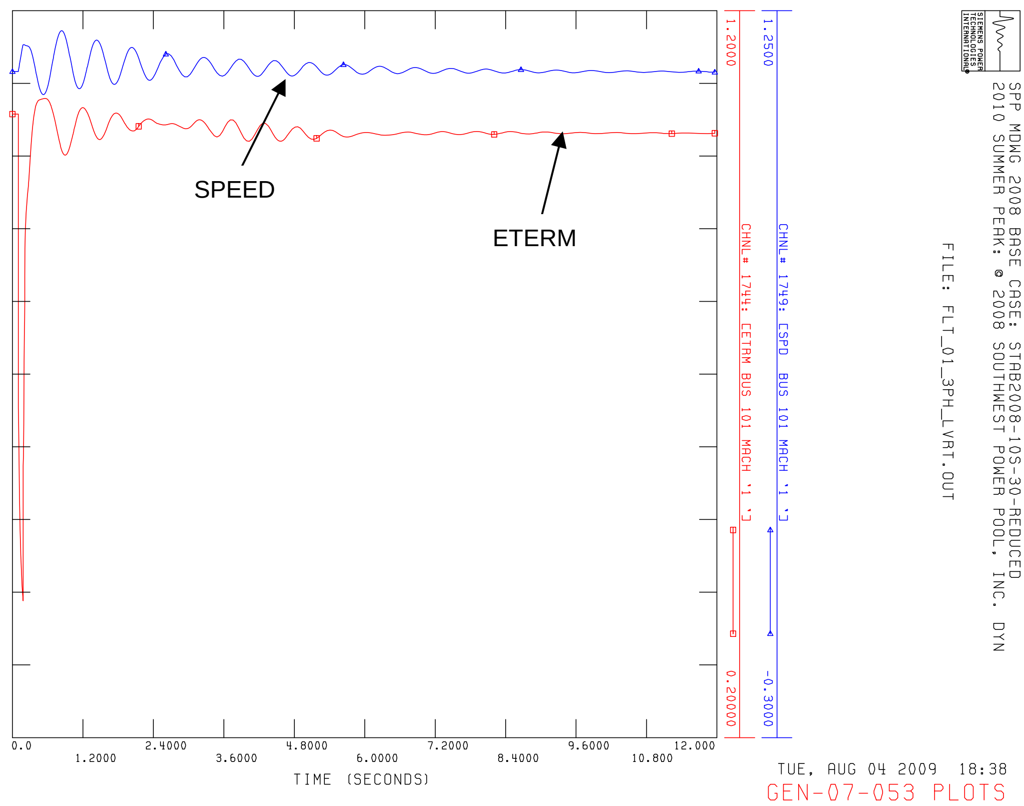

Figure 7-3 Voltage recovery after FLT01-3PH_LVRT (summer peak update model)

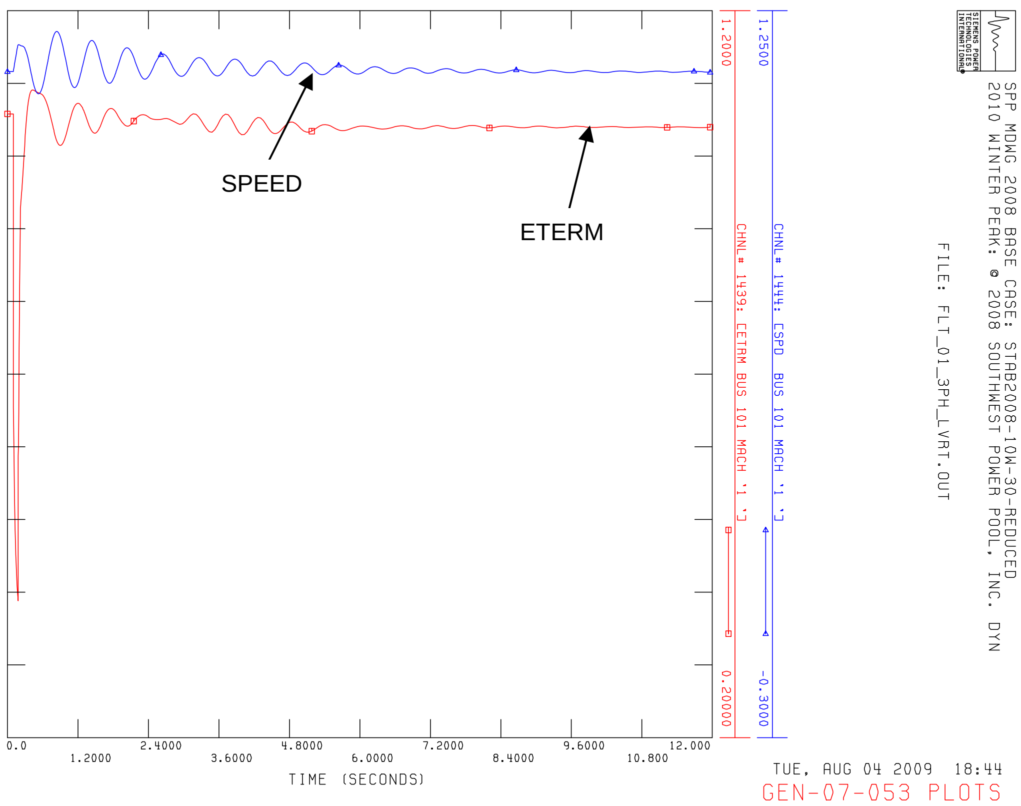

Figure 7-4 Voltage recovery after FLT01-3PH_LVRT (winter peak updated model)

The results of the FERC LVRT compliance are included in **Error! Reference source not found.** for reference.

8 CONCLUSIONS

The main objectives of this study were

1) To determine the need of reactive power compensation, if any, for the proposed wind farms
2) To determine the impact of proposed GEN-2007-053 generation on system stability and the nearby transmission system and generating stations.
3) To validate the compliance with FERC LVRT requirement for wind farms.

To achieve these objectives the following analyses were performed on the 2010 Summer Peak and 2010 Winter Peak system conditions with GEN-2007-053 in-service

- Power factor analysis for the selected contingencies.
- Transient stability analysis under various local and regional contingencies.
- LVRT performance under selected contingencies near POI.

Following is the summary of study findings:

Power factor analysis

The power factor analysis was performed to determine the need of additional reactive power compensation, if any, for the GEN-2007-053 wind farm projects. The results of power factor analysis indicated that GEN-2007-053 wind farm project, would require total of 30 Mvar shunt compensation (e.g. shunt capacitor banks) to meet the power factor requirement at the POI.

It should be noted that during this study the Gamesa 2.0 MW wind turbine generators in GEN-2007-053 wind farm project were assumed to be operated at fixed unity p.f. at machine terminal. The reactive power required to maintain the acceptable voltage and p.f. at the POI was provided by using shunt capacitors at the 34.5 kV collector bus. The WTGs reactive power capability would influence the sizing of the shunt capacitors. Optimization between the WTG reactive power capacity and the shunt capacitors was not performed in this study.

Stability Analysis

The stability analysis was performed to determine the impact, if any, of the proposed GEN-2007-053 project on the stability of the SPP system. The significant results of stability analysis are as follows:

- Undamped oscillations in the speed of GEN-2007-053 (150 MW comprised of Gamesa 2.0 MW WTGs) were observed following all the simulated faults. Further investigation indicated that the undamped oscillations are due to the user-written model used for representing the Gamesa wind turbine generators.
- Sensitivity analysis with a updated user-written model for Gamesa wind turbine was performed. The undamped oscillations in the speed of the equivalent wind generator were not observed.
- The system was found to be STABLE following all the simulated faults with the GEN-2007-053 project.

No stability criteria violations were observed following series of simulated faults at or near the POI after interconnection of the proposed project.

Based on the results of the stability analysis, it is concluded that the proposed wind farm does not adversely impact the stability of the SPP system.

FERC Order 661A Compliance – The proposed project (GEN-2007-053) complies with the latest FERC order on low voltage ride through for wind farms. With this arrangement, these wind farms would not trip off line by voltage relay actuation for local faults near the POI.

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