Southwest Power Pool

Impact Study for Generation Interconnection Request GEN–2006–017

SPP Tariff Studies
(#GEN-2006-017)

May 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-2006-017. 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.

Interconnection Facilities

The Impact Study has determined that if both GI request GEN-2006-014 and GEN-2006-17 sign an Interconnection Agreement and go into service, additional facilities will need to be constructed to interconnect GEN-2006-017.

For stability considerations discussed in the Impact Study, a fifth 161 kV line terminal will need to be added to the switching station that GEN-2006-014 wishes to interconnect with. This new line terminal will house the 161 kV line that presently terminates at MIPU's Maryville substation and MEC's Clarinda substation. For the purposes of interconnecting GEN-2006-017, the Maryville – Clarinda 161 kV line will need to have its line terminal rerouted from Maryville to the new switching station. The existing 161 kV line terminal at Maryville will be abandoned and left available for future use. The total minimum cost of these upgrades is listed as approximately $4,500,000 and is listed in Table 3. If GEN-2006-014 withdraws from the queue, the cost will be approximately $3,500,000 as shown in Table 2.

The Impact Study determined that a STATCOM or SVC device was not necessary for the studied Clipper turbines to meet FERC Order #661A with the addition of the new line terminal in the substation. The Customer will be required to install three capacitor banks for interconnection. There will be two 34.5 kV capacitor banks required on each of the Customer's two 161/34.5 kV transformers in the Customer substation. One capacitor bank will be sized at 18 Mvar. The second capacitor bank will be sized at 20 Mvar. A third capacitor bank will be sized at 161 kV, 32 Mvar. This capacitor bank will be located at the 161 kV switching station on the line terminal to the wind farm. This capacitor bank will be a Transmission Owner Interconnection Facility to be constructed by Aquila and 100% direct assigned to the Customer. The approximate cost of this capacitor bank is $500,000.

Table 1: Direct Assignment Facilities

Facility	ESTIMATED COST (2007 DOLLARS)
Customer – 161/34.5 kV Substation facilities.	*
Customer – 161 kV transmission line facilities between Customer facilities and MIPU 161 kV switching station.	*
Customer – Right-of-Way for Customer facilities.	*
Customer – Two (2) 34.5 kV, capacitor banks in Customer substation. Their sizes to be 18 Mvar and 20 Mvar.	*
MIPU – 161 kV, 32 Mvar capacitor bank in MIPU switching station.	$500,000
Total	*****

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

Table 2: Required Interconnection Network Upgrade Facilities (Assuming prior queued project withdraws)

Facility	ESTIMATED COST (2006 DOLLARS)
MIPU – Build 161 kV, 3-breaker ring bus switching station. Station to include breakers, switches, control relaying, high speed communications, all structures and metering and other related equipment.	$3,500,000
Total	**$3,500,000**

Table 3: Required Interconnection Network Upgrade Facilities (Assuming prior queued project stays in the queue)

Facility	ESTIMATED COST (2006 DOLLARS)
MIPU – Add two (2) 161 kV line and breaker terminals to the ring bus switching station built initially for request GEN-2006-014.	$1,000,000
Construct approximately 5 miles of 161 kV transmission line from Maryville substation to the new ring bus switching station built for GEN-2006-014.	$3,500,000
Total	**$4,500,000**

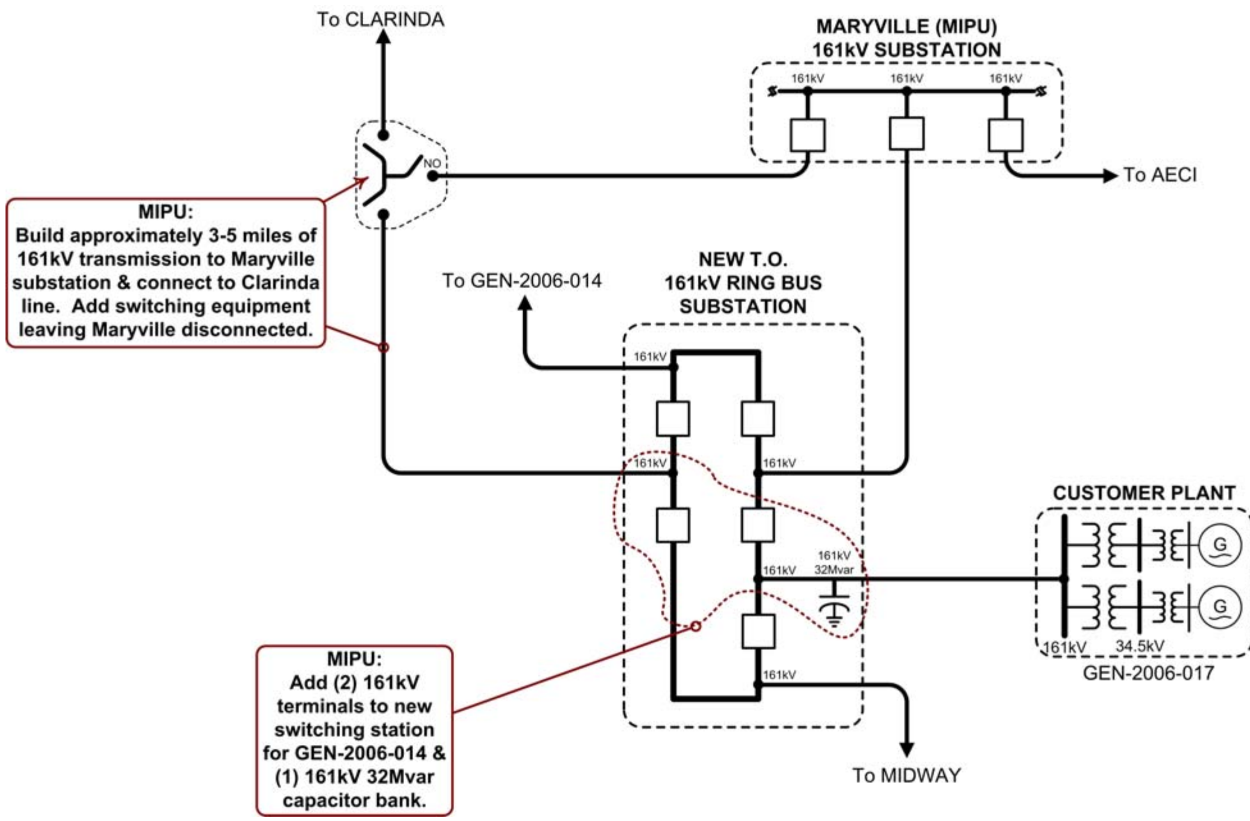

Figure 1: Proposed Interconnection
(Final substation design to be determined)

Powerflow Analysis

The power flow analysis from the Feasibility Study was conducted again due to the change in configuration of the transmission system. A powerflow analysis was conducted for the facility using modified versions of the 2008 & 2011 summer and winter peak, and 2016 summer peak models. The output of the Customer's facility was offset in each model by a reduction in output of existing online SPP generation. This method allows the request to be studied as an Energy Resource (ER) Interconnection request. The proposed in-service date of the generation is April 30, 2008. The available seasonal models used were through the 2016 Summer Peak of which is the end of the current SPP planning horizon.

The analysis of the Customer's project indicates that, given the requested generation level of 300 MW and location, additional criteria violations will occur on the existing MIPU, Associated Electric Cooperative Inc. (AECI), and Westar (WERE) transmission systems under steady state and contingency conditions in the peak seasons.

Issues concerning the feasibility of this request remain even after the reconfiguration of the transmission system. The Maryville – Midway 161 kV line has an emergency rating of 182 MVA, which would limit the export of 300 MW as well as the 300 MW from the prior queued project from the interconnection point. Mitigation of this constraint as well as the other network constraints in Table 4 will be addressed when the Customer requests transmission service for this facility under the SPP OATT.

In Table 5, a value of Available Transfer Capability (ATC) associated with each overloaded facility is included. These values may be used by the Customer to determine lower generation capacity levels that may be installed. When transmission service associated with this interconnection is evaluated, the loading of the facilities listed in this table may be greater due to higher priority reservations. When a facility is overloaded for more than one contingency, only the highest loading on the facility for each season is included in the table.

There are several other proposed generation additions in the general area of the Customer's facility. These local projects that were previously queued were assumed to be in service in this Feasibility Study. Those local projects that were previously queued and have advanced to nearly complete phases were included in this Feasibility Study.

Powerflow Methodology

The Southwest Power Pool (SPP) criteria states that: "The transmission system of the SPP region shall be planned and constructed so that the contingencies as set forth in the Criteria will meet the applicable *NERC Planning Standards* for System Adequacy and Security – Transmission System Table I hereafter referred to as NERC Table I) and its applicable standards and measurements".

Using the created models and the ACCC function of PSS\E, single contingencies in portions or all of the modeled control areas of MIPU, Westar (WERE), Kansas City Power & Light (KCPL), NPPD, OPPD, and AECI were applied and the resulting scenarios analyzed. This satisfies the 'more probable' contingency testing criteria mandated by NERC and the SPP criteria.

Table 4: Network Constraints

OWNER	NETWORK CONSTRAINT
AECI	'CLRNDA 5 161 - CRESTON5 161 161KV CKT 1'
AECI	'EAGLGRV869.0 - WRIGHT 869.0 69KV CKT 1'
AECI	'FAIRPORT - NODAWAY 161KV CKT 1'
AECI	'MOBERLY TAP - THOMAS HILL 161KV CKT 1'
AECI-MIPU	'MARYVILLE - MARYVILLE 161KV CKT 1'
MIPU	'ALABAMA5 161 - LAKE ROAD 161KV CKT 1'
MIPU	'G06-14 161 - MARYVILLE 161KV CKT 1'
MIPU	'MARYVILLE - SKIDMORE 69KV CKT 1'
MIPU	'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 1'
MIPU	'MIDWAY - ST JOE 161KV CKT 1'
WERE	'JARBALO JUNCTION SWITCHING STATION - STRANGER CREEK 115KV CKT 1'

Table 5. Contingency Analysis

ELEMENT	SEASON	RATE (MVA)	LOADING (%)	ATC (MW)	CONTINGENCY
2008 SUMMER PEAK					
'MOBERLY TAP - THOMAS HILL 161KV CKT 1'	08sp	372	113.5	0	'AECI-MTL10'
'G06-14 161 - MARYVILLE 161KV CKT 1'	08sp	182	196.0	0	'G06-14 161 - MIDWAY 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 1'	08sp	30	130.4	52	'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'
'MARYVILLE - MARYVILLE 161KV CKT 1'	08sp	200	172.9	95	'G06-14 161 - MIDWAY 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'	08sp	50	124.0	126	'FAIRPORT - NODAWAY 161KV CKT 1'
'ALABAMA5 161 - LAKE ROAD 161KV CKT 1'	08sp	153	106.2	186	'HAWTHORN - ST JOE 345KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	08sp	192	154.5	194	'G06-14 161 - MARYVILLE 161KV CKT 1'
'CLRNDA 5 161 - CRESTON5 161 161KV CKT 1'	08sp	146	104.7	232	'CRESTON5 161 - MARYVILLE 161KV CKT 1'
'MARYVILLE - SKIDMORE 69KV CKT 1'	08sp	51	106.8	250	'FAIRPORT - NODAWAY 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	08sp	167	114.8	261	'BASE CASE'
'FAIRPORT - NODAWAY 161KV CKT 1'	08sp	247	104.2	277	'G06-14 161 - MIDWAY 161KV CKT 1'
'FAIRPORT - NODAWAY 161KV CKT 1'	08sp	163	102.0	289	'BASE CASE'
2008 WINTER PEAK					
'G06-14 161 - MARYVILLE 161KV CKT 1'	08wp	182	203.7	0	'G06-14 161 - MIDWAY 161KV CKT 1'
'MARYVILLE - MARYVILLE 161KV CKT 1'	08wp	200	179.7	68	'G06-14 161 - MIDWAY 161KV CKT 1'
'G06-14 161 - MIDWAY 161KV CKT 1'	08wp	182	159.2	115	'MARYVILLE - MARYVILLE 161KV CKT 1'
'MIDWAY - ST JOE 161KV CKT 1'	08wp	182	149.6	145	'MARYVILLE - MARYVILLE 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 1'	08wp	30	115.7	172	'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	08wp	192	161.5	186	'G06-14 161 - MARYVILLE 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'	08wp	50	107.8	237	'FAIRPORT - NODAWAY 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	08wp	167	111.0	270	'BASE CASE'
2011 SUMMER PEAK					
'JARBALO JUNCTION SWITCHING STATION - STRANGER CREEK 115KV CKT 1'	11sp	240	111.9	0	'CRAIG - STRANGER CREEK 345KV CKT 1'
'G06-14 161 - MARYVILLE 161KV CKT 1'	11sp	182	199.4	0	'G06-14 161 - MIDWAY 161KV CKT 1'
'HUMBLTE869.0 - THOR8 69.0 69KV CKT 1'	11sp	41	203.6	0	'HOPE 5 161 161/69KV TRANSFORMER CKT 1'
'GOLDFLD869.0 - THOR8 69.0 69KV CKT 1'	11sp	41	208.2	0	'HOPE 5 161 161/69KV TRANSFORMER CKT 1'
'MOBERLY TAP - THOMAS HILL 161KV CKT 1'	11sp	372	104.5	0	'AECI-MTL10'

Table 5. Contingency Analysis (continued)

ELEMENT	SEASON	RATE (MVA)	LOADING (%)	ATC (MW)	CONTINGENCY
2011 SUMMER PEAK (continued)					
'ALABAMA5 161 - LAKE ROAD 161KV CKT 1'	11sp	153	118.9	0	'HAWTHORN - ST JOE 345KV CKT 1'
'WRI MID869.0 - WRIGHT 869.0 69KV CKT 1'	11sp	83	143.8	0	'HOPE 5 161 161/69KV TRANSFORMER CKT 1'
'WRIGHT 5 161 161/69KV TRANSFORMER CKT 1'	11sp	83	150.1	0	'HOPE 5 161 161/69KV TRANSFORMER CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 1'	11sp	30	124.7	82	'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'
'MARYVILLE - MARYVILLE 161KV CKT 1'	11sp	200	176.0	97	'G06-14 161 - MIDWAY 161KV CKT 1'
'G06-14 161 - MIDWAY 161KV CKT 1'	11sp	182	160.1	112	'MARYVILLE - MARYVILLE 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'	11sp	50	124.2	136	'FAIRPORT - NODAWAY 161KV CKT 1'
'MIDWAY - ST JOE 161KV CKT 1'	11sp	182	150.7	143	'MARYVILLE - MARYVILLE 161KV CKT 1'
'ALABAMA5 161 - NASHUA 161KV CKT 1'	11sp	153	107.9	149	'HAWTHORN - ST JOE 345KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	11sp	192	160.8	187	'G06-14 161 - MARYVILLE 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	11sp	167	122.1	246	'BASE CASE'
'MARYVILLE - SKIDMORE 69KV CKT 1'	11sp	51	106.1	257	'FAIRPORT - NODAWAY 161KV CKT 1'
'FAIRPORT - NODAWAY 161KV CKT 1'	11sp	163	102.2	288	'BASE CASE'
'FAIRPORT - NODAWAY 161KV CKT 1'	11sp	247	101.3	293	'G06-14 161 - MIDWAY 161KV CKT 1'
'EAGLGRV869.0 - WRIGHT 869.0 69KV CKT 1'	11sp	90	104.3	299	'HOPE 5 161 161/69KV TRANSFORMER CKT 1'
2011 WINTER PEAK					
'MARYVILLE - MARYVILLE 161KV CKT 1'	11wp	200	182.7	82	'G06-14 161 - MIDWAY 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 1'	11wp	30	122.8	106	'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'
'G06-14 161 - MIDWAY 161KV CKT 1'	11wp	182	153.8	132	'MARYVILLE - MARYVILLE 161KV CKT 1'
'G06-14 161 - MARYVILLE 161KV CKT 1'	11wp	182	206.8	145	'G06-14 161 - MIDWAY 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'	11wp	50	123.2	145	'FAIRPORT - NODAWAY 161KV CKT 1'
'MIDWAY - ST JOE 161KV CKT 1'	11wp	182	144.2	162	'MARYVILLE - MARYVILLE 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	11wp	192	167.0	180	'G06-14 161 - MARYVILLE 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	11wp	167	126.7	237	'BASE CASE'
2016 SUMMER PEAK					
'G06-14 161 - MARYVILLE 161KV CKT 1'	16sp	182	200.7	0	'G06-14 161 - MIDWAY 161KV CKT 1'
'MIDWAY - ST JOE 161KV CKT 1'	16sp	182	162.7	0	'G06-14 161 - MARYVILLE 161KV CKT 1'

Table 5. Contingency Analysis (continued)

ELEMENT	SEASON	RATE (MVA)	LOADING (%)	ATC (MW)	CONTINGENCY
2016 SUMMER PEAK (continued)					
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 1'	16sp	30	132.7	6	'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'
'ALABAMA5 161 - LAKE ROAD 161KV CKT 1'	16sp	153	112.6	71	'HAWTHORN - ST JOE 345KV CKT 1'
'MARYVILLE - MARYVILLE 161KV CKT 1'	16sp	200	177.2	96	'G06-14 161 - MIDWAY 161KV CKT 1'
'MARYVILLE (MARYVILL) 161/69/13.8KV TRANSFORMER CKT 2'	16sp	50	127.2	109	'FAIRPORT - NODAWAY 161KV CKT 1'
'G06-14 161 - MIDWAY 161KV CKT 1'	16sp	182	157.3	122	'MARYVILLE - MARYVILLE 161KV CKT 1'
'MIDWAY - ST JOE 161KV CKT 1'	16sp	182	147.9	152	'MARYVILLE - MARYVILLE 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	16sp	192	163.8	183	'G06-14 161 - MARYVILLE 161KV CKT 1'
'CLRNDA 5 161 - G06-14 161 161KV CKT 1'	16sp	167	126.1	238	'BASE CASE'
'MARYVILLE - SKIDMORE 69KV CKT 1'	16sp	51	107.9	244	'FAIRPORT - NODAWAY 161KV CKT 1'
'ALABAMA5 161 - NASHUA 161KV CKT 1'	16sp	153	100.7	287	'HAWTHORN - ST JOE 345KV CKT 1'
'FAIRPORT - NODAWAY 161KV CKT 1'	16sp	163	100.6	297	'BASE CASE'

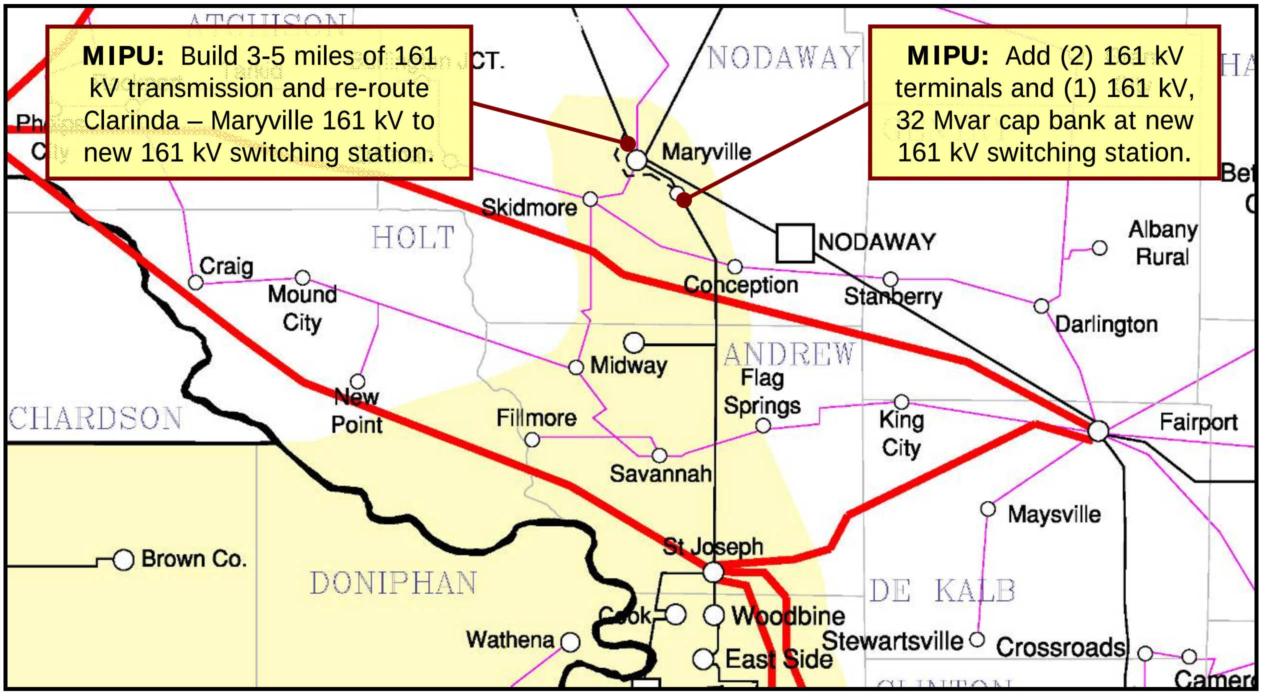

Figure 2. Map of the Local Area

IMPACT STUDY FOR GENERATION INTERCONNECTION REQUEST GEN-2006-017

FINAL REPORT

REPORT NO.: 2007-11454-R0
Issued: May 21, 2007

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ABB Inc – Grid Systems Consulting

Technical Report

Southwest Power Pool	**No.** 2006-11454-R0	
Impact Study for Generation Interconnection request GEN-2006-017	5/21/2007	# Pages 11

Author(s):	**Reviewed by:**	**Approved by:**
Shu Liu	Bill Quaintance	Willie Wong

Executive Summary

Southwest Power Pool (SPP) has commissioned ABB to perform a Generation Interconnection Impact study of a new 300 MW wind farm in Nodaway County, Missouri. This wind farm will be interconnected to a new station on the Maryville – Midway 161 kV transmission line, which is owned by Aquila, at a point approximately 5% of the distance from Maryville. This plant will comprise 120 Clipper 2.5 MW wind turbine generators. The interconnection impact study includes only stability analysis. 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 GEN-2006-017 to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2007 Winter Peak and the 2011 Summer Peak.

Based on the original transmission configuration, units of GEN-2006-014 and GEN-2006-017 will trip following FLT_1_3PH (loss of Maryville – POI 161 kV line) for both Summer Peak and Winter Peak conditions. GEN-2006-017 will remain on-line through all other simulated faults, and the SPP system will be stable following these faults in both Summer Peak and Winter Peak system conditions.

Shunt reactive compensation, regardless of size or location, is insufficient to eliminate voltage instability and resulting wind farm tripping for FLT_1_3PH. A system upgrade is required by rerouting the Maryville terminal of the Maryville to Clarinda 161 kV line to the GEN-2006-017 POI 161 kV bus. After moving this line, GEN-2006-014 and GEN-2006-017 remain on-line through all the simulated faults, and the SPP system will be stable following all faults in both Summer Peak and Winter Peak conditions.

To achieve 1.0 power factor at the POI, 18 MVAR and 20 MVAR of capacitors, respectively, are required at the two GEN-2006-017 substation 34.5 kV buses, and 32 MVAR of capacitors are required at the POI. A total of 70 Mvar of capacitors are required across these three locations.

Rev No.	Revision Description	Date	Authored by	Reviewed by	Approved by
0	Final Report	5/21/2007	Shu Liu	Bill Quaintance	Willie Wong
DISTRIBUTION: Charles Hendrix – Southwest Power Pool					

Based on the results of stability analysis it can be concluded that the proposed GEN-2006-017 project does not adversely impact the stability of the SPP system if the Maryville terminal of the Maryville to Clarinda 161kV line is moved to the GEN-2006-017 POI and shunt capacitors are added as mentioned above.

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

TABLE OF CONTENTS

1 INTRODUCTION

Southwest Power Pool (SPP) has commissioned ABB Inc. to perform a Generation Interconnection Impact study of a new 300 MW wind farm in Nodaway County, Missouri. This wind farm will be interconnected to a new station on the Maryville – Midway 161 kV transmission line at a point with approximately 5% of the distance from Maryville, which is owned by Aquila. This plant will comprise 120 Clipper 2.5 MW wind turbine generators. The interconnection impact study includes only the stability analysis. The feasibility (power flow) study was not performed as a part of this study.

The objective of the impact study is to evaluate the impact on system stability after connecting the GEN-2006-017 to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2007 Winter Peak and the 2011 Summer Peak. Figure 1-1 shows the Point of interconnection for the GEN-2006-017.

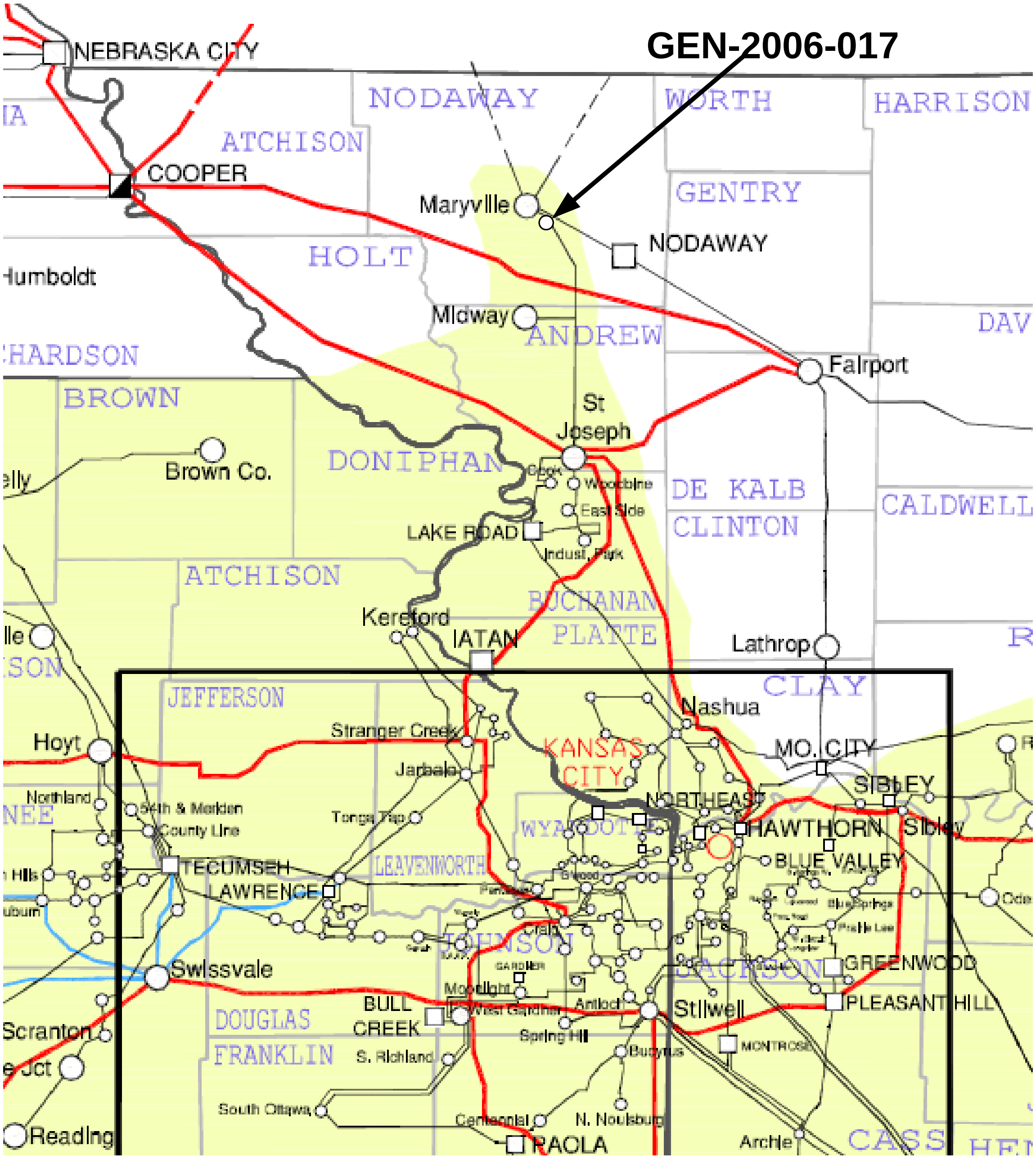

Figure 1-1: GEN-2006-017 Point of Interconnection

2 STABILITY ANALYSIS

In this study, ABB investigated the stability of the system for faults in the vicinity of the proposed plant as defined by SPP. The faults involve three-phase and single-phase faults cleared by primary protection, re-closing with the fault still on, and then permanently clearing the fault with primary protection.

2.1 STABILITY ANALYSIS METHODOLOGY

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

"Power system stability is defined as that condition in which the differences of the angular positions of synchronous machine rotors become constant following an aperiodic system disturbance."

In addition, new wind generators (which are usually asynchronous) are required to stay on-line following normally cleared faults at the Point of Interconnection (POI).

Stability analysis was performed using Siemens-PTI's PSS/E dynamics program V29. Three-phase and single-phase line faults were simulated for the specified durations, including re-closing, and the synchronous machine rotor angles were monitored to make sure they maintained synchronism following the fault removal. Stability of asynchronous machines was monitored as well.

Single-phase line faults were simulated with the standard method of applying fault impedance to the positive sequence network to represent the effect of the negative and zero sequence networks on the positive sequence network. The fault impedance was computed to give a positive sequence voltage at the fault location of approximately 60% of pre-fault voltage, which is a typical value.

2.2 STUDY MODEL DEVELOPMENT

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

Power Flow Case

SPP provided two (2) Pre-project PSS/E power flow cases called "*gen06-17_11sp_base.sav*" representing the Summer Peak conditions of the SPP system for the year 2011 and the "*gen06-17_07wp_base.sav*" representing the Winter Peak conditions of the SPP system for the year 2007.

The proposed GEN-2006-017 project is comprised of 120 Clipper 2.5 MW wind turbine generators. The units will be connected to a new station on the Maryville – Midway 161 kV transmission line by two two-winding 161/34.5 kV transformers and a 12.5-mile 161 kV transmission line. The proposed project was added to the Pre-project cases and the generation was dispatched by scaling down generation in area 151 by 300 MW. See Table 2-1 for details. Two power flow cases with GEN-2006-017 were established:

SP11-GEN-2006-017.SAV
WP07-GEN-2006-017.SAV

Figure 2-1 and Figure 2-2 show the power flow diagrams for the local area of Maryville - Midway 161 kV transmission line with GEN-2006-017 in-service (Summer Peak 2011 and Winter Peak 2007 system conditions, respectively).

Table 2-1: GEN-2006-017 project details

System condition	MW	Location	Point of Interconnection	Sink
Summer Peak	300	Nodaway County, Missouri	Maryville-Midway 161 kV transmission line	Area 151
Winter Peak	300	Nodaway County, Missouri	Maryville-Midway 161 kV transmission line	Area 151

Wind Farm Power Flow Model

The GEN-2006-017 wind farm has 120 Clipper 2.5 MW wind turbine generators. Two groups of wind turbine-generators which include 58 and 62 turbines respectively are modeled as two single machines. Each equivalent generator is connected to a 161/34.5 kV transformer through single equivalent GSU transformer and a single equivalent collector branch. These two 161/34.5 kV transformers are connected to the full SPP system model through a 12.5-mile 161 kV transmission line. The detailed process of wind farm model development is included in Appendix A.

Stability Database

SPP provided the stability database in the form of a PSS/E dynamic dyr data file "*gen06-17_11sp_base.dyr*" to model the Summer Peak stability dynamics database for 2011 and "*gen06-17_07wp_base.dyr*" to model the Winter Peak stability dynamics database for the year 2007. Along with the above-mentioned files, idev and batch files were also provided to compile and link user-written models. The provided files required the use of PSS/E version 29.

The stability data for GEN-2006-017 was appended to the Pre-project snapshot. 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.

The power flow and stability model representations for GEN-2006-017 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 10 seconds.

Table 2-2: List of Faults for Stability Analysis

FAULT	FAULT DESCRIPTION
FLT_1_3PH	a. Apply 3-phase fault at the GEN-2006-017 bus (572). b. Clear fault after 5 cycles by removing the line from GEN-2006-017 (572) to Maryville (59251). 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 GEN-2006-017 bus (572). b. Clear fault after 5 cycles by removing the line from GEN-2006-017 (572) to Maryville (59251). 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 GEN-2006-017 bus (572). b. Clear fault after 5 cycles by removing the line from GEN-2006-017 (572) to Midway (59252). 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 GEN-2006-017 bus (572). b. Clear fault after 5 cycles by removing the line from GEN-2006-017 (572) to Midway (59252). c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_5_3PH	a. Apply 3-phase fault at the Maryville bus (59251). b. Clear fault after 5 cycles by removing the line from Maryville (59251) to AECI Maryville (96097). 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 Maryville bus (59251). b. Clear fault after 5 cycles by removing the line from Maryville (59251) to AECI Maryville (96097). 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 Maryville bus (59251). b. Clear fault after 5 cycles by removing the line from Maryville (59251) to Clarinda (63826). 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 Maryville bus (59251). b. Clear fault after 5 cycles by removing the line from Maryville (59251) to Clarinda (63826). 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 AECI Maryville bus (96097). b. Clear fault after 5 cycles by removing the line from AECI Maryville (96097) to AECI Nodaway (96104). 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_10_1PH	a. Apply 1-phase fault at the AECI Maryville bus (96097). b. Clear fault after 5 cycles by removing the line from AECI Maryville (96097) to AECI Nodaway (96104). 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 AECI Maryville bus (96097). b. Clear fault after 5 cycles by removing the line from AECI Maryville (96097) to Creston (66560). 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 AECI Maryville bus (96097). b. Clear fault after 5 cycles by removing the line from AECI Maryville (96097) to Creston (66560). 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 Midway bus (59252). b. Clear fault after 5 cycles by removing the line from Midway (59252) to St. Joseph (59253). 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 Midway bus (59252). b. Clear fault after 5 cycles by removing the line from Midway (59252) to St. Joseph (59253). c. Wait 20 cycles, and then re-close the line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b), and remove fault.
FLT_15_3PH	a. Apply 3-phase fault at the St. Joe bus (59199). b. Clear fault after 5 cycles by tripping the St. Joe 345/161kV autotransformer(59253-59199-59370-CK1).
FLT_16_1PH	a. Apply 1-phase fault at the St. Joe bus (59199). b. Clear fault after 5 cycles by tripping the St. Joe 345/161kV autotransformer (59253-59199-59370-CK1).
FLT_17_3PH	a. Apply 3-phase fault at the Fairport bus (96076). b. Clear fault after 5 cycles by removing the line from Fairport (96076) to AECI PQ wind farm (115). 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 3-phase fault at the Fairport bus (96076). b. Clear fault after 5 cycles by removing the line from Fairport (96076) to AECI PQ wind farm (115). 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.

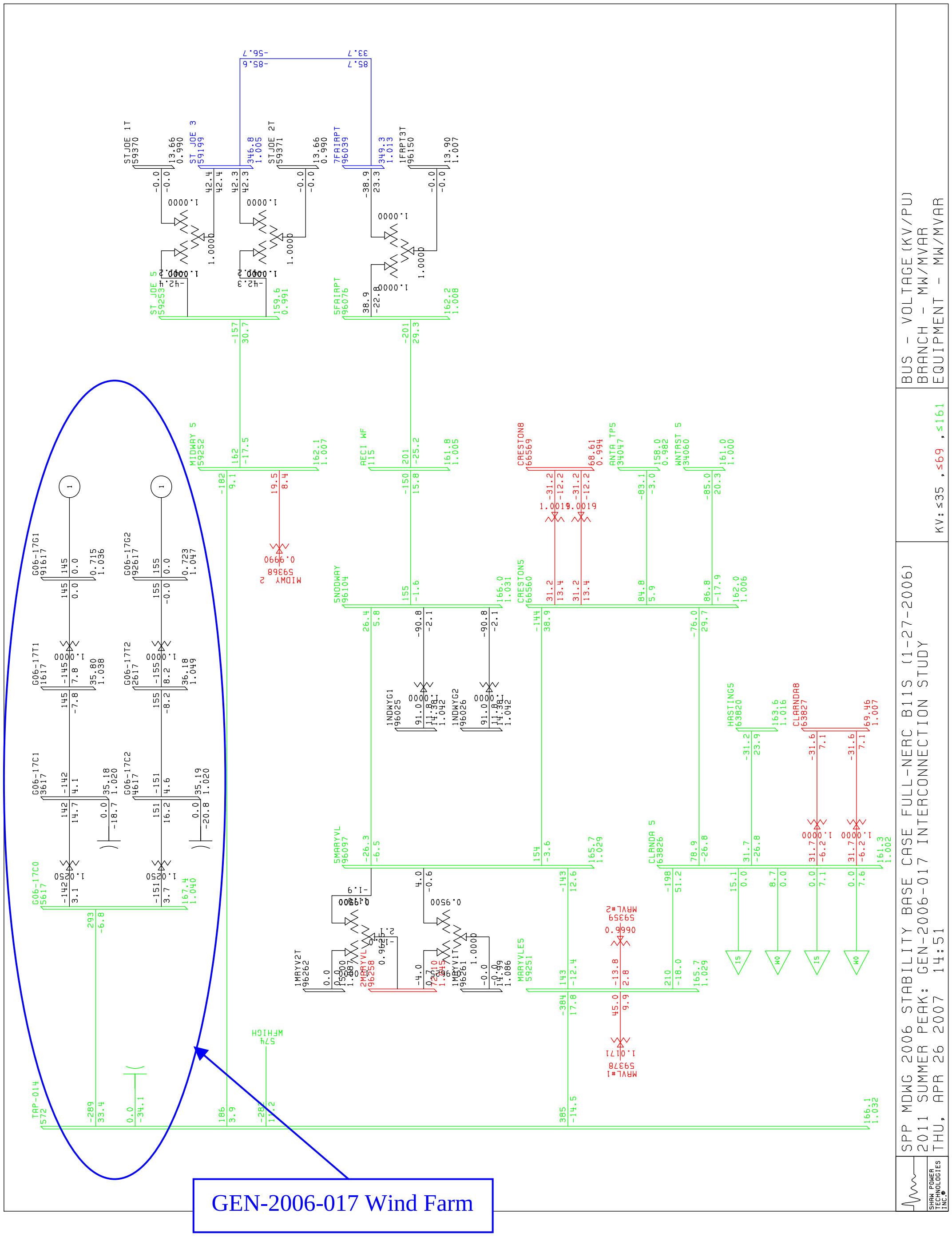

Figure 2-1: Power flow diagram for GEN-2006-017 with Base Configuration (Summer Peak 2011)

ABB

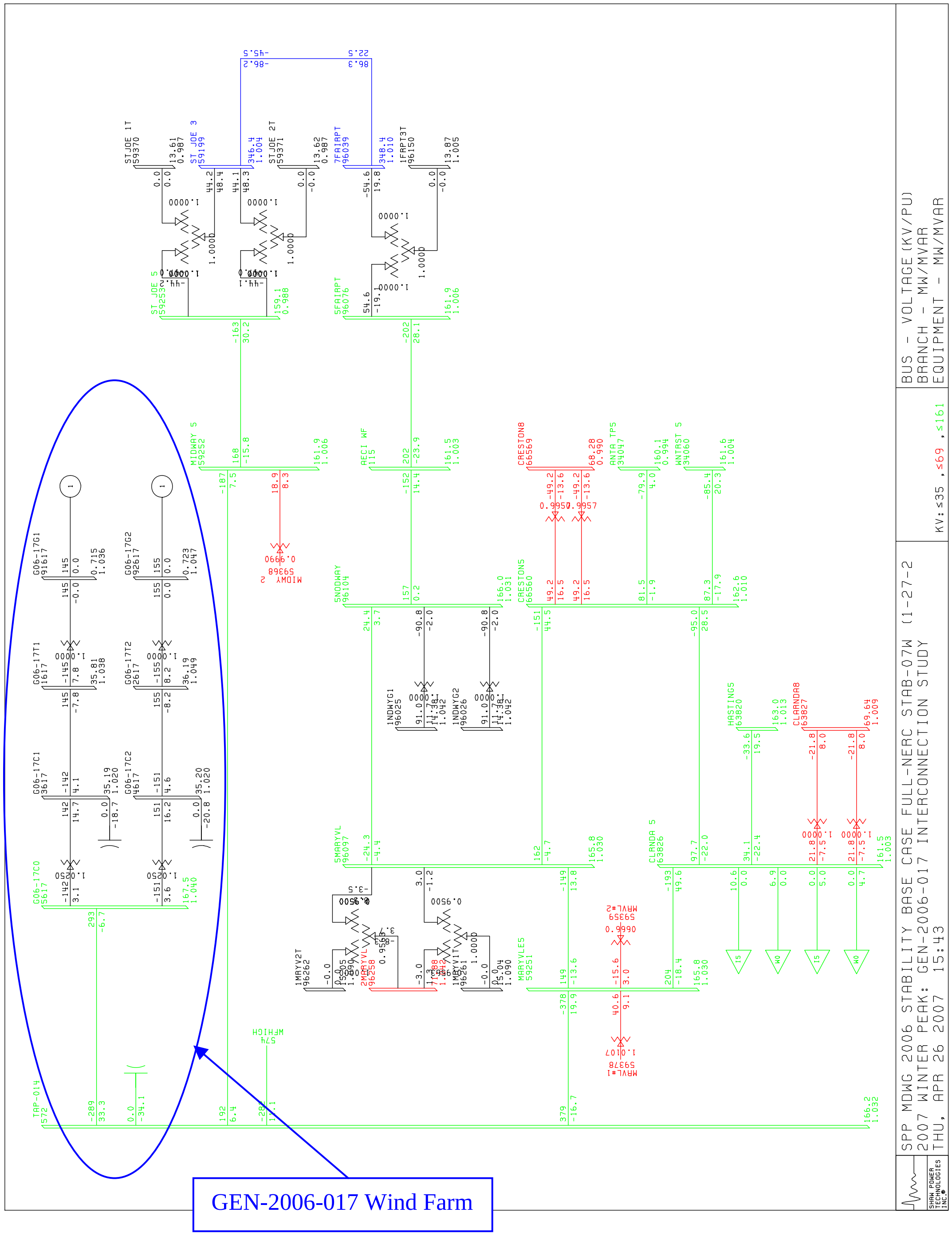

Figure 2-2: Power flow diagram for GEN-2006-017 with Base Configuration (Winter Peak 2007)

ABB

2.3 STUDY RESULTS

2.3.1 INITIAL RESULTS

The results for all the disturbances simulated are summarized in Table 2-3.

The plots for all the simulated faults are included in Appendix C.

Table 2-3: Results for Stability Analysis

FAULT	Summer Peak 2011	Winter Peak 2007
FLT_1_3PH	GEN-2006-014 Tripped GEN-2006-017 Tripped Unit at Bus #90100 Tripped	GEN-2006-014 Tripped GEN-2006-017 Tripped
FLT_2_1PH	STABLE	STABLE
FLT_3_3PH	Unit at Bus #90100 Tripped	STABLE
FLT_4_1PH	STABLE	STABLE
FLT_5_3PH	Unit at Bus #90100 Tripped	STABLE
FLT_6_1PH	STABLE	STABLE
FLT_7_3PH	Unit at Bus #90100 Tripped	STABLE
FLT_8_1PH	STABLE	STABLE
FLT_9_3PH	Unit at Bus #90100 Tripped	STABLE
FLT_10_1PH	STABLE	STABLE
FLT_11_3PH	Unit at Bus #90100 Tripped	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

For Summer Peak system condition, the unit at bus #90100 of GEN-2006-014 tripped due to low frequency following FLT_1_3PH, FLT_3_3PH, FLT_5_3PH, FLT_7_3PH, FLT_9_3PH, and FLT_11_3PH. Since PSS/E does not provide accurate frequency estimation during transients, the under frequency tripping strategy of this unit was disabled. Voltage tripping relays we left in service.

The subsequent results of the simulations indicate that units of GEN-2006-014 and GEN-2006-017 will be tripped by voltage relay action following FLT_1_3PH for both Summer Peak and Winter Peak system conditions. GEN-2006-017 will remain on-line through the other simulated faults, and the SPP system will be stable following these faults in both Summer Peak and Winter Peak system conditions**.**

2.3.2 INVESTIGATION OF FLT_1_3PH

While steady-state and thermal analysis are not a standard part of this impact study, when flows on transmission lines exceed their thermal ratings by large amounts (e.g. loadings greater than 150% of rating), steady-state voltage instability and collapse can occur. In this case, a 300 MW wind farm is being connected to the 182 MVA Maryville-Midway 161 kV transmission line, close to the Maryville end. If the segment from the POI to Maryville trips, all 300 MW has to flow on the relatively weak and high-impedance line to Midway. This flow cannot be carried by this line, and voltage collapse occurs (i.e. voltage instability, power flow case cannot solve).

To see if shunt reactive compensation can at least allow a power flow solution and avoid voltage collapse, the QV curve technique can be used. A reactive power source is placed at a bus, and the desired voltage schedule is varied over a large range. The Mvar injection required to hold each desire voltage is recorded, and the data are plotted on a graph. See **Figure 2-3** showing QV curves for the POI 161 kV bus and Midway 161 kV bus for the pre-project 2007 winter peak case with the POI-Maryville 161 kV line out of service. The minimum point on a QV curve represents the marginal stability point and the amount of Mvar injection required to just barely achieve steady-state stability. The part of the curve to the left of this point (i.e. negative slope) is the unstable part of the curve. The power system is unstable in that region. The part of the curve to the right is the stable region. As shown in **Figure 2-3**, the system is stable for voltages above 0.94 per unit, and at least 5-10 Mvar of additional shunt compensation is needed to achieve steady-state stability for this contingency.

However, when the post-project case is considered, a dire situation is found (**Figure 2-4**). For reactive power injection at the Midway 161 kV bus, the reactive deficiency is 116 Mvar, but more importantly, even if this reactive compensation were added, the system is stable only for voltages above 1.06 per unit, which is not a feasible operating condition. For reactive power injection at the POI 161 kV bus, the stable voltage region is above 1.14 per unit. Similar results were found for the 2011 summer peak case.

This problem is reflected in the dynamic simulation of FLT_1_3PH by voltages that do not recover after fault clearing, resulting in tripping of wind turbines and then very high swings in voltage.

This analysis shows that addition of shunt reactive compensation (e.g. capacitors or SVC) cannot solve the voltage instability problem and wind farm tripping that is the result of an extremely overloaded transmission system after adding the proposed GEN-2006-017 project.

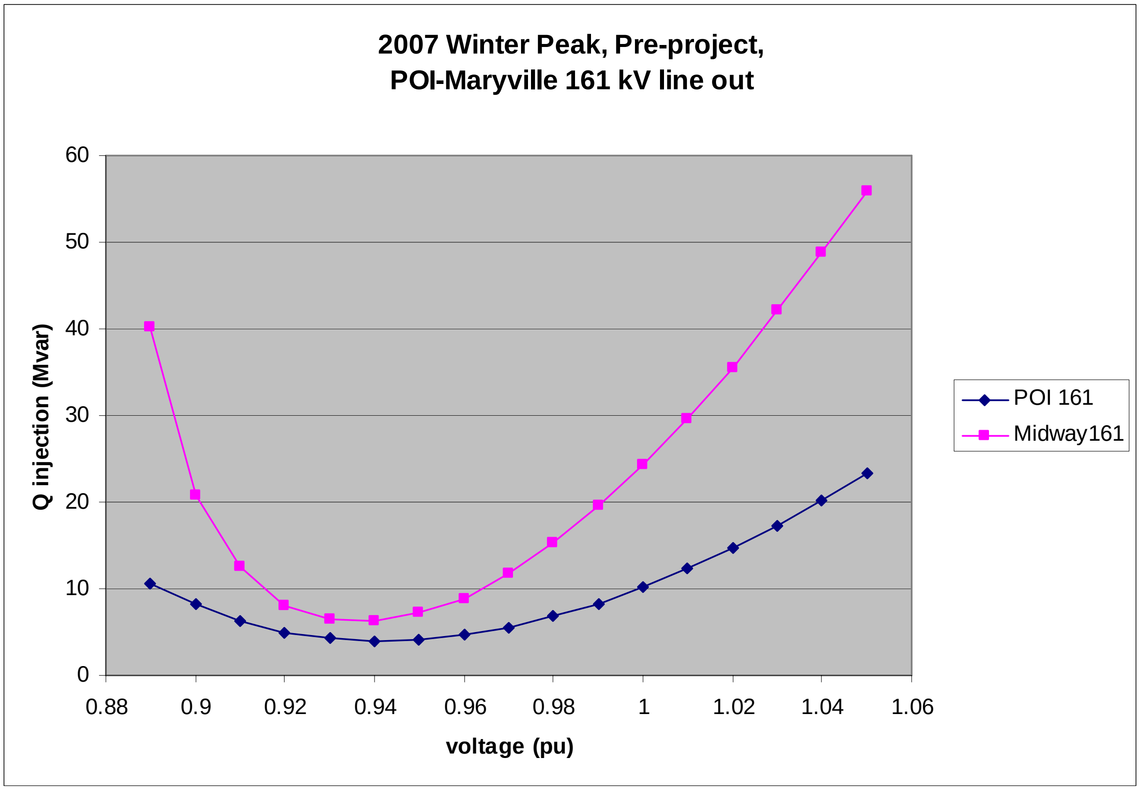

Figure 2-3: QV Curves for 2007 Winter Peak, Pre-project

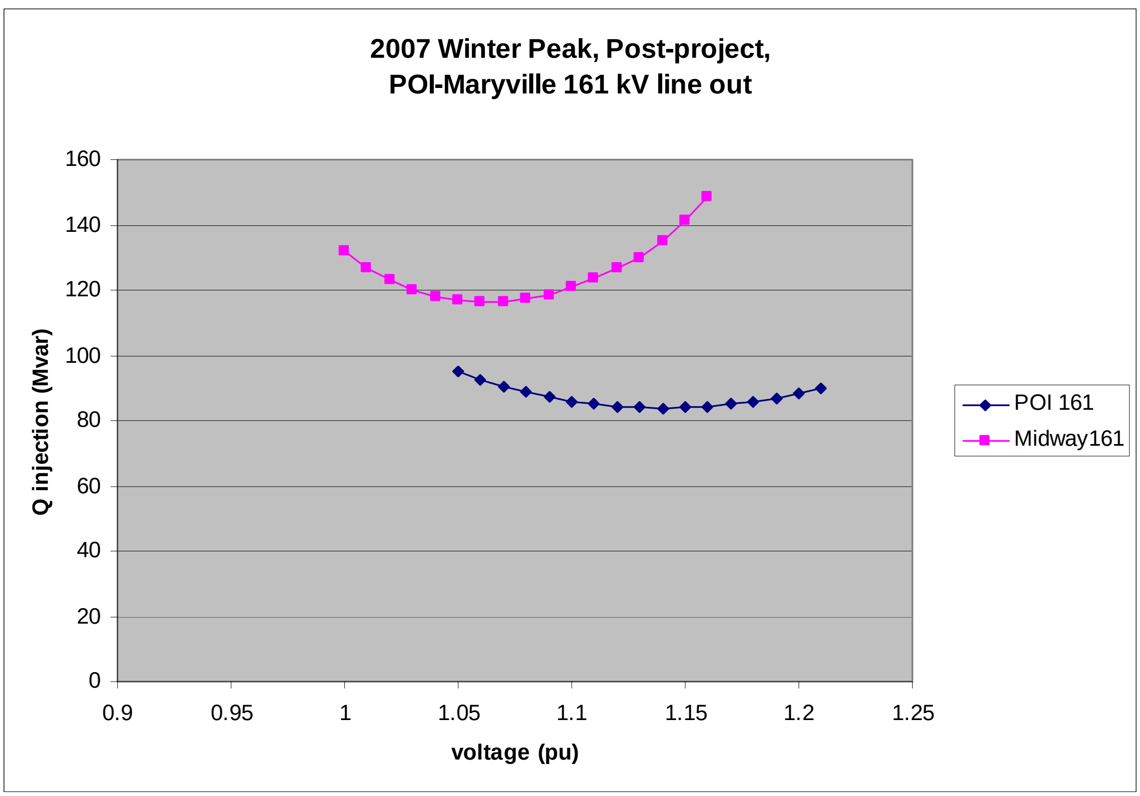

Figure 2-4: QV Curves for 2007 Winter Peak, Post-project

2.3.3 Transmission Reconfiguration

To prevent the loss of GEN-2006-014 and GEN-2006-017 following FLT_1_3PH, an alternative transmission configuration was modeled by moving the Maryville terminal of the Maryville to Clarinda 161kV line to the GEN-2006-017 POI. **Figure 2-5** and **Figure 2-6** show the resulting power flow diagrams after rerouting this line (Summer Peak 2011 and Winter Peak 2007, respectively).

FLT_7_3PH and FLT_8_1PH are changed based on the new transmission configuration, as shown in **Table 2-4**.

Table 2-4: Faults FLT_7_3PH and FLT_8_1PH with Alternative Configuration

FAULT	FAULT DESCRIPTION
FLT_7_3PH	a. Apply 3-phase fault at the GEN-2006-017 bus (572). b. Clear fault after 5 cycles by removing the line from GEN-2006-017 (572) to Clarinda (63826). 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 GEN-2006-017 bus (572). b. Clear fault after 5 cycles by removing the line from GEN-2006-017 (572) to Clarinda (63826). 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.

The results for all disturbances simulated with the alternative configuration are summarized in **Table 2-5**. All results are stable with no wind turbine tripping.

The plots for all the simulated faults are included in Appendix D.

Table 2-5: Results for Stability Analysis with Alternative Configuration

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

The GEN-2006-017 will remain on-line through all the simulated faults and the SPP system will be stable following all these faults in both Summer Peak and Winter Peak conditions by moving the Maryville terminal of the Maryville to Clarinda 161 kV line to the GEN-2006-017 POI bus.

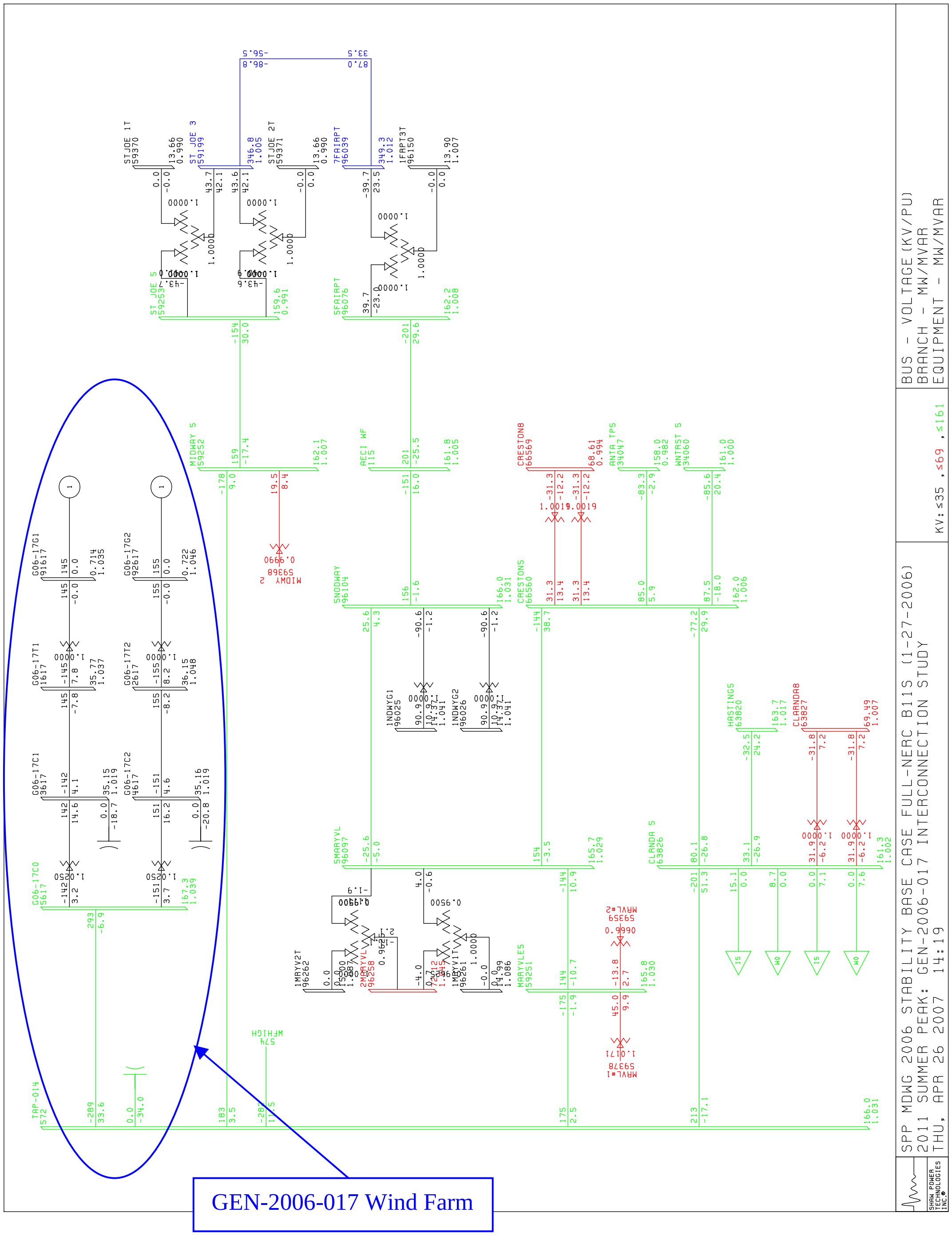

Figure 2-5: Power flow diagram for GEN-2006-017 with Alternate Configuration (Summer Peak 2011)

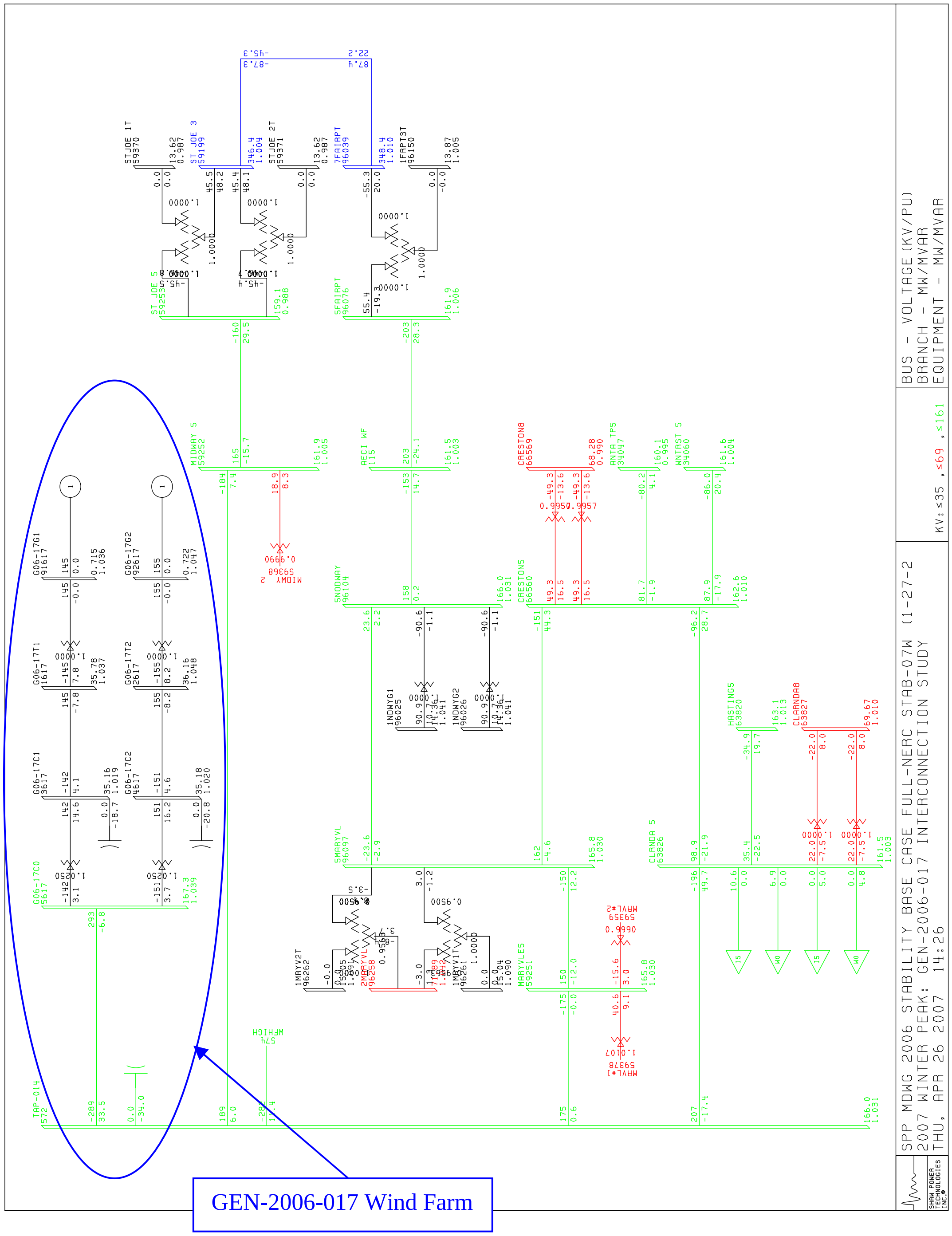

Figure 2-6: Power flow diagram for GEN-2006-017 with Alternate Configuration (Winter Peak 2007)

2.4 ADDITIONAL REACTIVE POWER REQUIREMENTS

The Clipper 2.5 MW wind turbine generators are modeled a 1.0 power factor. To supply the reactive power losses of the wind farm collector system and transformers and achieve 1.0 power factor at the POI 161 kV bus, 18 MVAR and 20 MVAR of capacitors, respectively, are required at the two wind farm 34.5 kV buses, and 32 MVAR of capacitors are required at the POI. The result is a total of 70 Mvar of shunt capacitors across three locations. The capacitors at the POI are required because of the long radial transmission line from the project substation to the POI.

Additional shunt compensation, such as SVC or STATCOM, was insufficient to fix the original problems with FLT1, thus requiring the rerouting of the Maryville to Clarinda 161 kV line. With this line rerouting, no additional shunt compensation is needed beyond the capacitors mentioned above.

3 CONCLUSIONS

The objective of this study is to evaluate the impact on system stability after connecting GEN-2006-017 to the interconnection point and its effect on the nearby transmission system and generating stations. The study is performed on two system scenarios: 2007 Winter Peak and the 2011 Summer Peak.

Based on the original transmission configuration, units of GEN-2006-014 and GEN-2006-017 will trip following FLT_1_3PH (loss of Maryville – POI 161 kV line) for both Summer Peak and Winter Peak conditions. GEN-2006-017 will remain on-line through all other simulated faults, and the SPP system will be stable following these faults in both Summer Peak and Winter Peak system conditions**.**

Shunt reactive compensation, regardless of size or location, is insufficient to eliminate voltage instability and resulting wind farm tripping for FLT_1_3PH. A system upgrade is required by rerouting the Maryville terminal of the Maryville to Clarinda 161 kV line to the GEN-2006-017 POI 161 kV bus. After moving this line, GEN-2006-014 and GEN-2006-017 remain on-line through all the simulated faults, and the SPP system will be stable following all faults in both Summer Peak and Winter Peak conditions**.**

To achieve 1.0 power factor at the POI, 18 MVAR and 20 MVAR of capacitors, respectively, are required at the two GEN-2006-017 substation 34.5 kV buses, and 32 MVAR of capacitors are required at the POI. A total of 70 Mvar of capacitors are required across these three locations.

Based on the results of stability analysis it can be concluded that the proposed GEN-2006-017 project does not adversely impact the stability of the SPP system if the Maryville terminal of the Maryville to Clarinda 161kV line is moved to the GEN-2006-017 POI and shunt capacitors are added as mentioned above.

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 - SIMULATION PLOTS FOR STABILITY ANALYSIS (ORIGINAL TRANSMISSION CONDITION)

APPENDIX D - SIMULATION PLOTS FOR STABILITY ANALYSIS (MOVING THE TERMINAL OF THE MARYVILLE TO CLARINDA 161 KV LINE FROM MARYVILLE TO THE POI)