



***Impact Study for Generation
Interconnection Request
GEN – 2005 – 005***

***SPP Tariff Studies
(#GEN-2005-005)***

November 2005

Summary

Pursuant to the tariff and at the request of the Southwest Power Pool (SPP) ABB Inc. Electric 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-2005-005. 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.



IMPACT STUDIES FOR GENERATION INTERCONNECTION REQUEST GEN-2005-005

Prepared for: SOUTHWEST POWER POOL

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Submitted by:

**ABB Inc., Electric Systems Consulting
940 Main Campus Drive, Suite 300
Raleigh, NC 27606**

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Author(s):

Amit Kekare

Reviewed by:

William Quaintance

Approved by:

Willie Wong

Executive Summary:

Southwest Power Pool (SPP) has requested ABB to perform an interconnection impact study for 18 MW capacity addition to a 100 MW wind farm in Woodward County, Oklahoma. The wind farm will be connected to the switching station located on the Mooreland Power Station (WFEC) – Woodward (OG&E) 138 kV line. As per the developer’s request, the 18 MW additional generation is studied by using Siemens 2.3 MW Mk II 60 Hz wind turbine generators. Several faults were simulated on the SPP system for Summer Peak 2009 and Winter Peak 2006 system conditions.

The SPP system would be stable following all the simulated faults. Based on the results of the stability analysis, it is concluded that the proposed capacity addition of 18 MW with Siemens Mk II turbines does not adversely impact the stability of the SPP system. The wind farm stays online for all the faults simulated. The present low-voltage ride-through capability of the Siemens Mk II should suffice for the GEN-2005-005 wind farm to avoid unnecessary and nuisance tripping of generation following transmission faults.

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

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1 INTRODUCTION

SPP has requested an interconnection impact study for an 18 MW capacity addition to a 100 MW wind farm in Woodward County, Oklahoma. The original wind farm has queue number GEN-2001-037. The wind farm will be connected to the switching station located on the Mooreland Power Station (WFEC) – Woodward (OG&E) 138 kV line. As per developer's request, the 18 MW additional generation is studied by using Siemens 2.3 MW Mk II 60 Hz wind turbine generators. 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 additional 18 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: 2006 Winter Peak and the 2009 Summer Peak, provided by SPP. Figure 1.1 shows the proposed 18 MW addition to the 100 MW GEN-2001-037 Wind Farm.

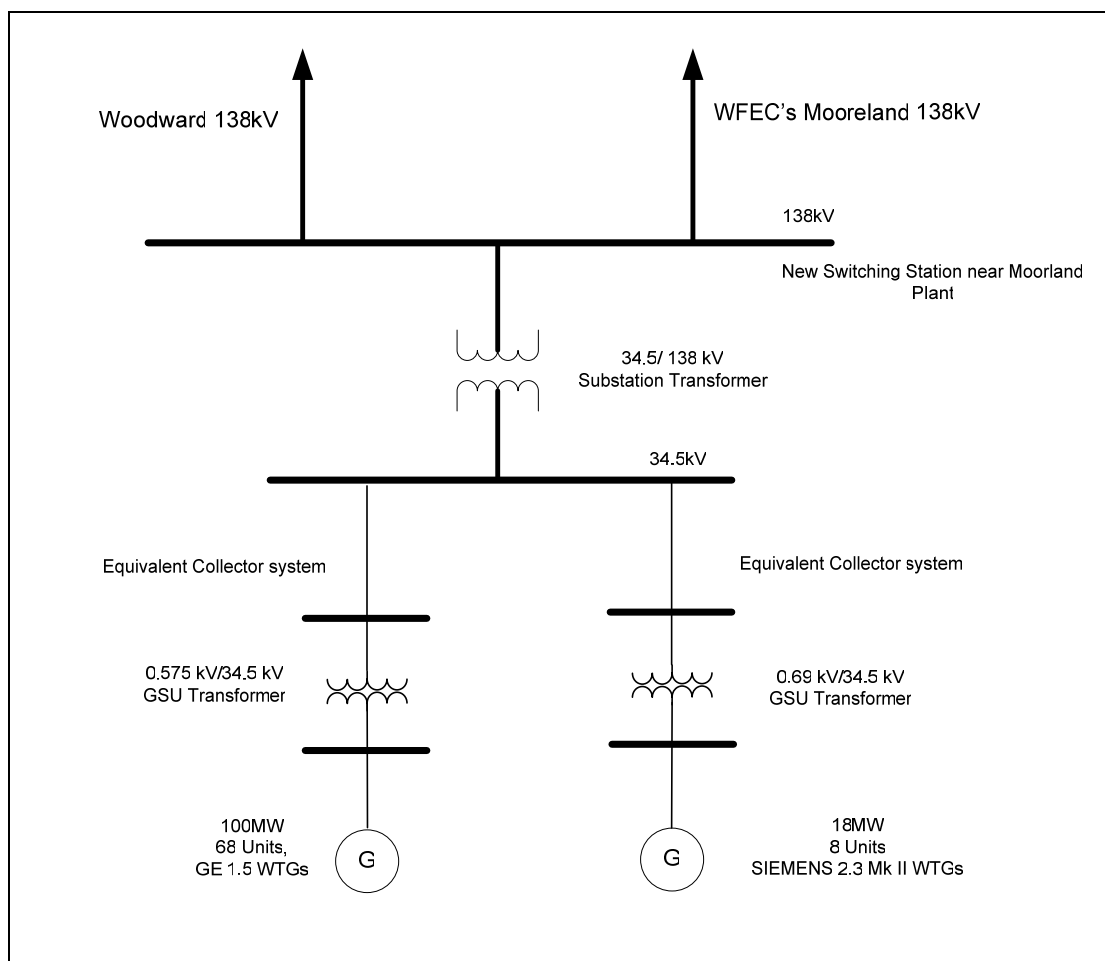


Figure 1.1: Proposed 18 MW generation expansion at Woodward Co.

2 STABILITY ANALYSIS

In this stability 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, reclosing 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.”

Stability analysis was performed using Siemens-PTI’s PSS/E dynamics program V29. All the stability simulations were performed by modeling the new wind machines using the Siemens 2.3 MW Mk II model provided by SPP.

Disturbances such as three-phase and single-phase line faults were simulated for the specified durations, including reclosing, and the synchronous machine rotor angles were monitored to make sure they maintained synchronism following the fault removal.

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.

The ability of the wind generators to stay connected to the grid during the disturbances and during the fault recovery was also monitored. 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 Siemens 2.3 MW Mk II model is equipped with over/under voltage relays and over/under frequency relays. All the faults that resulted in the tripping of the proposed wind farm were rerun with the tripping disabled to verify the stability of the farm.

2.2 Study Model Development

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

Collector System Development:

The developer provided a detailed layout of the wind farm collector system and wind turbine generators. While it is not practical to model all the wind turbine generators in the wind

farm individually in the case for the power systems stability analysis, the detailed data was used to calculate two equivalent machines of 100 MW (with GE-DFIG WTGs) and 18 MW (Siemens 2.3 MW Mk II WTGs) on the main feeder (see Figure 1.1). The detailed plant layout was modeled in PSS/E power flow, and short-circuit analysis was used to determine the Thevenin equivalent impedance of the wind farm at the low side of the substation transformers. This impedance was separated into three parts: an equivalent generator step-up transformer, equivalent source impedance, and the remainder representing an equivalent 34.5 kV collector system impedance¹. An equivalent line charging capacitance is added to the equivalent collector impedance to give the same Mvar injection at the substation in the equivalent model as in the detailed model.

Appendix A shows the wind farm equivalent model data used for the load flow case development.

The load flow data for the equivalent machines is obtained from the package provided by SPP for Siemens 2.3 MW Mk II.

Power Flow Cases Development:

SPP provided two PSS/E power flow cases called “SPP_2006_Winter_stability.sav” representing the winter conditions of the SPP system for the year 2006 and the “SPP_2009_Summer_stability.sav” representing the summer conditions of the SPP system for the year 2009. At the request of SPP some prior-queued generation was modeled accurately with latest PSS/E models for GE-DFIG and Vestas (V80A)- (Version July 2005). The cases provided were updated to make them compatible with the dynamics database provided. Some changes were made to the cases to prevent initial conditions suspect and initialization errors during dynamic simulations. These changes resulted in two pre-project cases (SP09-PRE-2005-005.SAV & WP06-PRE-2005-005.SAV)

An equivalent of the proposed wind farm (GEN 2005-005) comprising 8 units of Siemens 2.3 MW Mk II wind turbines (18 MW) was added to the pre-project cases. The resulting cases were used as the base cases for the GEN 2005-005 study.

Wind farm modeling:

The proposed wind farm is modeled in the load flow cases as one equivalent wind turbine generator of 18 MW. The equivalent machine has a generator step-up transformer (GSU) modeled as a lumped equivalent as shown in Figure 1.1. A common substation transformer

¹ This separation of the Thevenin equivalent is purely aesthetic. For example, if the impedance of all the *individual* GSU transformers were to change, it would not be sufficient to simply change the impedance of the *equivalent* GSU transformer. One would need to change the individual GSU impedances in the detailed model and recalculate the Thevenin impedance. Subtracting out the new equivalent GSU impedance would leave a new and different equivalent collector system impedance. The only instance where one can expect the equivalent collector impedance to stay the same when changing the GSUs is if all wind generators were identically distant in impedance from the substation, which is rarely the case.

with the 100 MW GE-DFIG section of the wind farm and a generator step-up transformer were modeled per data provided by developer.

Stability database Development

SPP provided the stability database in the form of a PSS/E dynamic raw data file “SPP_2006_Winter_stability.dyr” to model the winter stability dynamics database for 2006 and “SPP_2009_Summer_stability.dyr” to model the summer stability dynamics database for the year 2009. 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 latest PSS/E GE and Vestas (V80A) dynamic models were used to model the prior queued wind farms per SPP request. The PSS/E GE and Vestas (V80A) models require execution of an IPLAN program that adds the GSU and the generator on the low side of GSU (0.575/ 0.690 kV). This IPLAN program also generates a dynamic data file (*.dyr) for the machines. The direct dispatch (100.0%) for MW generation and voltage control mode for Mvar generation were used. The under-voltage and frequency trip settings have been retained. The cases developed after the addition of these prior queued plants were used as the base cases for the study of the proposed wind farm (2005-005). The proposed wind farm was added to the base cases to develop the cases used for the study.

The load flow cases were adjusted to overcome network non-convergence during the simulation of some of the faults. The Miles City DC line and Lamar DC line were equivalenced because they were causing problems for the simulations.

The Siemens 2.3 MK II model data was also added to the pre-project database to create the databases with the new generation. Dynamic data for the equivalent 18 MW generator models is listed in Appendix B.

The dynamic model provided for Siemens 2.3 MK II wind turbines is still a work in progress. The DOCU and DYDA outputs are still not complete. The basic dynamic simulation code seems to work fine for most conditions.

Finally, two cases were developed by adding the proposed wind farm with Siemens 2.3 MK II to the two pre-project cases established:

SP09-2005-005.SAV

WP06-2005-005.SAV

Low voltage ride through capability:

It is important to note that the Siemens 2.3 MK II model (provided by SPP) includes under / over-voltage and frequency trip relays in the model. The under voltage settings are the most critical. The following voltage settings were obtained from the model packages supplied by SPP.

Table 2.1: Siemens 2.3 MW Mk II Voltage Trip settings

Under / Over voltage settings (per unit)	Time Delay (seconds)
0.15	0.150
0.70	1.000
0.90	5.000
1.10	1.000
1.20	0.200

Table 2.2 lists the disturbances simulated for stability analysis. All transmission lines were assumed to have reclosing enabled.

Table 2.2: Description of Faults with Wind Farm at 18 MW

Fault Name	Fault Description
FAULT_1_3PH	3PH Fault on Mooreland - GEN-2001-037 Wind Farm 138kV line near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55785. 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_2_1PH	SLG Fault on Mooreland - GEN-2001-037 Wind Farm 138kV line near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55785. 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_3_3PH	3PH Fault on the Mooreland (55999) - Iodine (55957) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55957. 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_4_1PH	SLG Fault on the Mooreland (55999) - Iodine (55957) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55957. 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 Name	Fault Description
FAULT_5_3PH	3PH Fault on the Mooreland (55999) – Morewood Switch (56001) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56001. 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_6_1PH	SLG Fault on the Mooreland (55999) – Morewood Switch (56001) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56001. 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_7_3PH	3PH Fault on the Morewood Switch (56001)-Elk City (54121) 138kV line, near Morewood a. Apply Fault at the Morewood Bus(56001). b. Clear Fault after 5 cycles by removing the line from 56001-54121. 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_8_1PH	SLG Fault on the Morewood Switch (56001)-Elk City (54121) 138kV line, near Morewood a. Apply Fault at the Morewood Bus(56001). b. Clear Fault after 5 cycles by removing the line from 56001-54121. 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_9_3PH	3PH Fault on the Mooreland (55999) – Taloga (56065) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56065. 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_10_1PH	SLG Fault on the Mooreland (55999) – Taloga (56065) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56065. 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_11_3PH	3PH Fault on the Mooreland (55999) – Glass Mtn. (54788) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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 Name	Fault Description
FAULT_12_1PH	SLG Fault on the Mooreland (55999) – Glass Mtn. (54788) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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_13_3PH	3PH Fault on the Mooreland (55999) – Cedardale (55848) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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_14_1PH	SLG Fault on the Mooreland (55999) – Cedardale (55848) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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_15_3PH	Fault on the Elk City (54121) – Clinton North (54148), 138kV line, near Elk City. a. Apply fault at the Elk City (54121). b. Clear fault after 5 cycles by removing the line from 54121-54148. 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_16_1PH	SLG Fault on the Elk City (54121) – Clinton North (54148), 138kV line, near Elk City. a. Apply fault at the Elk City (54121). b. Clear fault after 5 cycles by removing the line from 54121-54148. 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_17_3PH	3PH Fault on the Elk City (54121) – Clinton AFB (54109), 138kV line, near Elk City a. Apply fault at the Elk City bus (54121). b. Clear fault after 5 cycles by removing line from 54121-54109 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FAULT_18_1PH	SLG Fault on the Elk City (54121) – Clinton AFB (54109), 138kV line, near Elk City a. Apply fault at the Elk City bus (54121). b. Clear fault after 5 cycles by removing line from 54121-54109 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

Fault Name	Fault Description
FAULT_19_3PH	3 PH Fault on the FPLSWTCH (55785) – WOODWRD4 (54785) 138kV line a. Apply fault at the FPLSWTCH (55785) b. Clear fault after 5 cycles by removing line from 55785 - 54785 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.
FAULT_20_3PH	3 PH Fault on the FPLSWTCH (55785) – MOORLND4 (55999) 138kV line a. Apply fault at the FPLSWTCH (55785) b. Clear fault after 5 cycles by removing line from 55785 - 55999 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.

2.3 Stability Results

The results for all the disturbances simulated are summarized in Table 2.3 and 4.

The SPP system would be stable following all the simulated faults. For certain faults, wind farms in the local area tripped on undervoltage (for e.g. 96 MW generation at GEN-2001-014 or 120 MW generation at GEN-2002-005 or 100 MW generation at GEN-2001-037).

The faults for which local area wind farms were tripped for undervoltage were repeated by disabling the voltage trip relay models associated with these wind farms. When undervoltage protection is disabled, all wind turbine-generators must stay online. Some of these no-tripping cases resulted in unstable machines. The unstable faults were repeated on the case without GEN-2005-005. The results were the same before addition of proposed wind farm. Based on the results of the stability analysis, it is concluded that the interconnection of the wind farm at 18 MW with Siemens 2.3 MK II wind turbines does not adversely impact the stability of the SPP system. The proposed wind farm stays online for all the faults simulated. The present low-voltage ride-through capability of the Siemens 2.3 MK II should suffice for the GEN-2005-005 wind farm to avoid unnecessary and nuisance tripping of generation following transmission faults.

2.4 VESTAS MODEL ISSUE

The Vestas wind turbine controls in PSS/E (version July 2005) include a feature that will move the variable rotor resistance to its maximum value if the voltage goes too low. This has the effect of reducing the reactive power drawn by the induction generator, and thus increasing the voltage. However, for a weak system condition, the voltage may jump up significantly following the reduction in reactive power drawn by the machine. This large increase in voltage will then move the resistance back into variable mode. Thus, the machine terminal voltage, real and reactive power and may jump up and down at a high frequency, producing “scribbles” or noise in the plots (See Figure 2.1).

Whether or not the implementation of this control is accurate in the PSS/E model is unknown. It is also unknown if this control is adjustable on the real equipment for weaker system conditions. The wind farm developer should consult Vestas and be sure that this issue is addressed at commissioning.

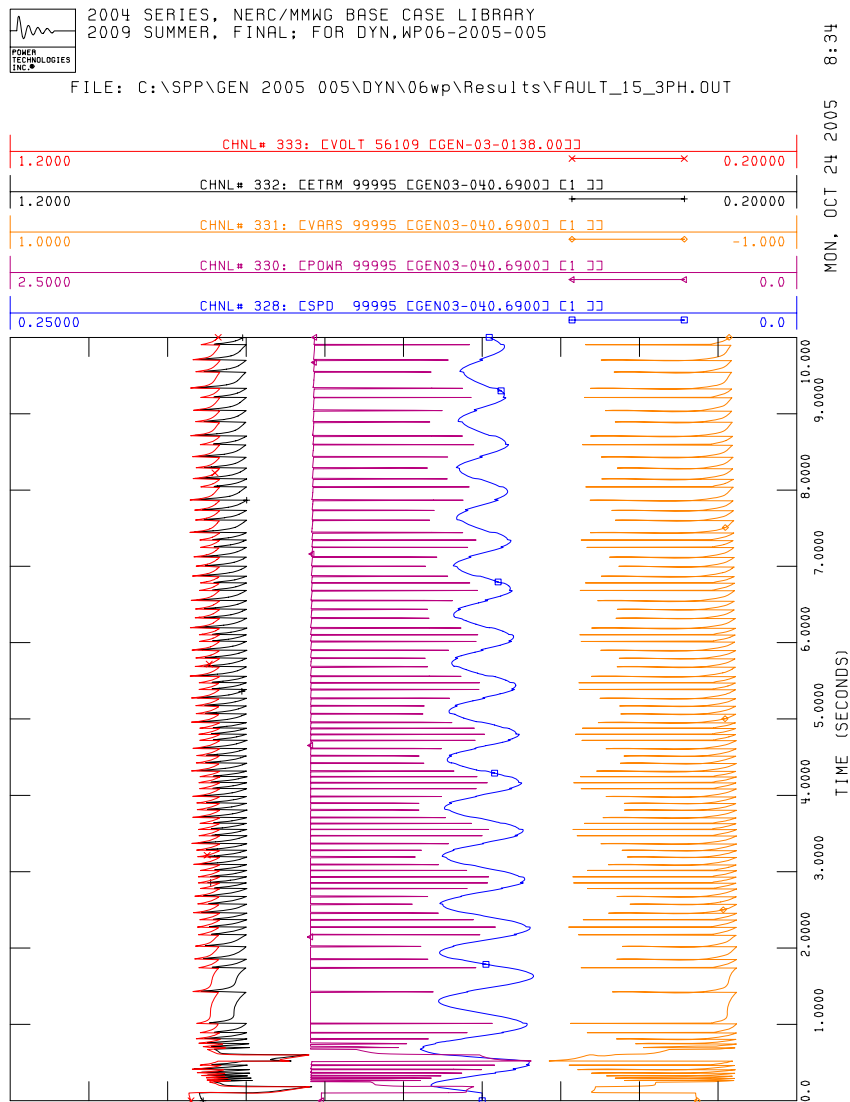


Figure 2.1: Vestas Model Parameters for ‘Fault_15_3PH’

Table 2.3: Summary of Results for Summer Peak 2009

Fault Name	Fault Description	Summer Peak 2009 With GEN-2005-005
FAULT_1_3PH	3PH Fault on Mooreland - GEN-2001-037 Wind Farm 138kV line near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55785. 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.	MACHINE 1 AT BUS 99997 [MORE_100 0.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_2_1PH	SLG Fault on Mooreland - GEN-2001-037 Wind Farm 138kV line near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55785. 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.	BUS 56108 DISCONNECTED AT TIME = 0.679
FAULT_3_3PH	3PH Fault on the Mooreland (55999) - Iodine (55957) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55957. 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.	BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_4_1PH	SLG Fault on the Mooreland (55999) - Iodine (55957) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55957. 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.	BUS 56108 DISCONNECTED AT TIME = 0.675
FAULT_5_3PH	3PH Fault on the Mooreland (55999) – Morewood Switch (56001) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56001. 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.	MACHINE 1 AT BUS 99997 [MORE_100 0.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263

Fault Name	Fault Description	Summer Peak 2009 With GEN-2005-005
FAULT_6_1PH	SLG Fault on the Mooreland (55999) – Morewood Switch (56001) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56001. 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.	BUS 56108 DISCONNECTED AT TIME = 0.679
FAULT_7_3PH	3PH Fault on the Morewood Switch (56001)-Elk City (54121) 138kV line, near Morewood a. Apply Fault at the Morewood Bus(56001). b. Clear Fault after 5 cycles by removing the line from 56001-54121. 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.	BUS 56106 DISCONNECTED AT TIME = 0.679
FAULT_8_1PH	SLG Fault on the Morewood Switch (56001)-Elk City (54121) 138kV line, near Morewood a. Apply Fault at the Morewood Bus(56001). b. Clear Fault after 5 cycles by removing the line from 56001-54121. 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.	Stable
FAULT_9_3PH	3PH Fault on the Mooreland (55999) – Taloga (56065) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56065. 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.	MACHINE 1 AT BUS 99997 [MORE_100 0.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_10_1PH	SLG Fault on the Mooreland (55999) – Taloga (56065) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56065. 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.	BUS 56108 DISCONNECTED AT TIME = 0.521 BUS 56106 DISCONNECTED AT TIME = 0.679 MACHINE 1 AT BUS 99997 [MORE_1000.5750] TRIPPED AT TIME = 0.7500
FAULT_11_3PH	3PH Fault on the Mooreland (55999) – Glass Mtn. (54788) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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.	MACHINE 1 AT BUS 99997 [MORE_100 0.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263

Fault Name	Fault Description	Summer Peak 2009 With GEN-2005-005
FAULT_12_1PH	SLG Fault on the Mooreland (55999) – Glass Mtn. (54788) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. c. Wait 20 cycles, and then re-close the line in (b) into the fault. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	BUS 56108 DISCONNECTED AT TIME = 0.679
FAULT_13_3PH	3PH Fault on the Mooreland (55999) – Cedardale (55848) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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.	MACHINE 1 AT BUS 99997 [MORE_100 0.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_14_1PH	SLG Fault on the Mooreland (55999) – Cedardale (55848) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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.	BUS 56108 DISCONNECTED AT TIME = 0.679
FAULT_15_3PH	Fault on the Elk City (54121) – Clinton North (54148), 138kV line, near Elk City. a. Apply fault at the Elk City (54121). b. Clear fault after 5 cycles by removing the line from 54121-54148. 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.	BUS 56106 DISCONNECTED AT TIME = 0.263
FAULT_16_1PH	SLG Fault on the Elk City (54121) – Clinton North (54148), 138kV line, near Elk City. a. Apply fault at the Elk City (54121). b. Clear fault after 5 cycles by removing the line from 54121-54148. 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.	Stable
FAULT_17_3PH	3PH Fault on the Elk City (54121) – Clinton AFB (54109), 138kV line, near Elk City a. Apply fault at the Elk City bus (54121). b. Clear fault after 5 cycles by removing line from 54121-54109 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	BUS 56106 DISCONNECTED AT TIME = 0.263

Fault Name	Fault Description	Summer Peak 2009 With GEN-2005-005
FAULT_18_1PH	SLG Fault on the Elk City (54121) – Clinton AFB (54109), 138kV line, near Elk City a. Apply fault at the Elk City bus (54121). b. Clear fault after 5 cycles by removing line from 54121-54109 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	Stable
FAULT_19_3PH	3 PH Fault on the FPLSWTCH (55785) – WOODWRD4 (54785) 138kV line a. Apply fault at the FPLSWTCH (55785) b. Clear fault after 5 cycles by removing line from 55785 - 54785 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_20_3PH	3 PH Fault on the FPLSWTCH (55785) – MOORLND4 (55999) 138kV line a. Apply fault at the FPLSWTCH (55785) b. Clear fault after 5 cycles by removing line from 55785 - 55999 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	MACHINE 1 AT BUS 99997 [MORE_100 0.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263

Note:-**Bus 56108: 96 MW generation GEN-2001-014****Bus 56106: 120 MW generation GEN-2002-005****Bus 99997: 100 MW generation GEN-2001-037**

Table 2.4: Summary of Results for Winter Peak 2006

Fault Name	Fault Description	Winter Peak 2006 With GEN-2005-005
FAULT_1_3PH	3PH Fault on Mooreland - GEN-2001-037 Wind Farm 138kV line near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55785. 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.	MACHINE 1 AT BUS 99997 [MORE_1000.5750] TRIPPED AT TIME = 0.7000 BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_2_1PH	SLG Fault on Mooreland - GEN-2001-037 Wind Farm 138kV line near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55785. 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.	Stable
FAULT_3_3PH	3PH Fault on the Mooreland (55999) - Iodine (55957) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55957. 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.	BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_4_1PH	SLG Fault on the Mooreland (55999) - Iodine (55957) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus (55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 55957. 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.	BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_5_3PH	3PH Fault on the Mooreland (55999) – Morewood Switch (56001) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56001. 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.	BUS 56108 DISCONNECTED AT TIME = 0.263

Fault Name	Fault Description	Winter Peak 2006 With GEN-2005-005
FAULT_6_1PH	SLG Fault on the Mooreland (55999) – Morewood Switch (56001) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56001. 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.	Stable
FAULT_7_3PH	3PH Fault on the Morewood Switch (56001)-Elk City (54121) 138kV line, near Morewood a. Apply Fault at the Morewood Bus(56001). b. Clear Fault after 5 cycles by removing the line from 56001-54121. 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.	BUS 56106 DISCONNECTED AT TIME = 0.679
FAULT_8_1PH	SLG Fault on the Morewood Switch (56001)-Elk City (54121) 138kV line, near Morewood a. Apply Fault at the Morewood Bus(56001). b. Clear Fault after 5 cycles by removing the line from 56001-54121. 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.	Stable
FAULT_9_3PH	3PH Fault on the Mooreland (55999) – Taloga (56065) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56065. 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.	BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_10_1PH	SLG Fault on the Mooreland (55999) – Taloga (56065) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 56065. 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.	Stable
FAULT_11_3PH	3PH Fault on the Mooreland (55999) – Glass Mtn. (54788) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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.	BUS 56108 DISCONNECTED AT TIME = 0.263

Fault Name	Fault Description	Winter Peak 2006 With GEN-2005-005
FAULT_12_1PH	SLG Fault on the Mooreland (55999) – Glass Mtn. (54788) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. c. Wait 20 cycles, and then re-close the line in (b) into the fault. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	Stable
FAULT_13_3PH	3PH Fault on the Mooreland (55999) – Cedardale (55848) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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.	MACHINE 1 AT BUS 99997 [MORE_1000.5750] TRIPPED AT TIME = 0.7000
FAULT_14_1PH	SLG Fault on the Mooreland (55999) – Cedardale (55848) 138kV line, near Mooreland a. Apply Fault at the Mooreland Bus(55999). b. Clear Fault after 5 cycles by removing the line from 55999 - 54788. 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.	Stable
FAULT_15_3PH	Fault on the Elk City (54121) – Clinton North (54148), 138kV line, near Elk City. a. Apply fault at the Elk City (54121). b. Clear fault after 5 cycles by removing the line from 54121-54148. 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.	BUS 56106 DISCONNECTED AT TIME = 0.263
FAULT_16_1PH	SLG Fault on the Elk City (54121) – Clinton North (54148), 138kV line, near Elk City. a. Apply fault at the Elk City (54121). b. Clear fault after 5 cycles by removing the line from 54121-54148. 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.	Stable
FAULT_17_3PH	3PH Fault on the Elk City (54121) – Clinton AFB (54109), 138kV line, near Elk City a. Apply fault at the Elk City bus (54121). b. Clear fault after 5 cycles by removing line from 54121-54109 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	BUS 56106 DISCONNECTED AT TIME = 0.263

Fault Name	Fault Description	Winter Peak 2006 With GEN-2005-005
FAULT_18_1PH	SLG Fault on the Elk City (54121) – Clinton AFB (54109), 138kV line, near Elk City a. Apply fault at the Elk City bus (54121). b. Clear fault after 5 cycles by removing line from 54121-54109 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	Stable
FAULT_19_3PH	3 PH Fault on the FPLSWTCH (55785) – WOODWRD4 (54785) 138kV line a. Apply fault at the FPLSWTCH (55785) b. Clear fault after 5 cycles by removing line from 55785 - 54785 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	BUS 56108 DISCONNECTED AT TIME = 0.263
FAULT_20_3PH	3 PH Fault on the FPLSWTCH (55785) – MOORLND4 (55999) 138kV line a. Apply fault at the FPLSWTCH (55785) b. Clear fault after 5 cycles by removing line from 55785 - 55999 c. Wait 20 cycles, and then re-close line in (b) into the fault. d. Leave fault on for 5 cycles, then trip the line in (b) and remove fault.	BUS 56108 DISCONNECTED AT TIME = 0.263

Note:-**Bus 56108: 96 MW generation GEN-2001-014****Bus 56106: 120 MW generation GEN-2002-005****Bus 99997: 100 MW generation GEN-2001-014**

3 STUDY CONCLUSIONS

Based on the results of the stability analysis, it is concluded that the interconnection of the proposed wind farm at 18 MW does not adversely impact the stability of the SPP system. The wind farm stays online for all the faults simulated. The present low-voltage ride-through capability of the Siemens 2.3 MK II should keep the GEN-2005-005 wind farm on line during most system events, which will avoid unnecessary and nuisance tripping of generation following transmission faults.

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

APPENDIX A – COLLECTOR SYSTEM



Appendix A.1. Collector System for the Siemens 2.3 MK II Machines

Substation Main Transformers data:

72/ 96/ 120 MVA

138/34.5 kV

15.0% @ 100 MVA (System Base)

Collector system Equivalent 1:

R = 0.06548

X = 0.07827

B = 0.00500

(On 100 MVA base)

GSU Equivalent 1:

2600 kVA times 8 turbines equals 20.80 MVA

34.5/0.690

5.75% @ 20.80 MVA

APPENDIX B – STABILITY MODEL PARAMETERS

PSS/E Dynamic Data for Equivalent Siemens 2.3 MK II 18 MW Generator

Base and Loadflow Information

Prated	2.30	Machine Active Power Rating (MW)	MBASE
Vrated	0.69	Stator Voltage Rating (kV)	
Busbar	90200	Connection busbar number	
Gen ID	1	Generator Identifier	
Rg	0	Generator Resistance in Loadflow (pu)	RSORCE
Xg	0.2000	Generator Reactance in Loadflow (pu)	XSORCE
Srated	2.6	Unit Transformer Rating (MVA)	Note 1
Rt	0.0082	Unit Transformer Resistance (pu)	Note 1
Xt	0.0580	Unit Transformer Reactance (pu)	Note 1

ICONS	Value	Description	Ref:
M	1	Model Version Number	
M+1	1	Reactive control mode (0=fixed, 1=voltage, 2 & 3 not in use)	
M+2	1	Enable Under-voltage relay 1	
M+3	1	Enable Under-voltage relay 2	
M+4	1	Enable Under-voltage relay 3	
M+5	1	Enable Over-voltage relay 1	
M+6	1	Enable Over-voltage relay 2	
M+7	1	Enable Under-frequency relay 1	
M+8	1	Enable Under-frequency relay 2	
M+9	1	Enable Over-frequency relay 1	

CONs	Value	Description	Ref:
J	18.0251		
J+1	1.0927	Generator Inertia Constant (MW.s/MVA)	
J+2	14.3349	Rotor Inertia Constant (MW.s/MVA)	
J+3	0.1458	Shaft Damping	
J+4	138.49	Shaft Stiffness	
J+5	1.3169		
J+6	1.1109		
J+7	22		
J+8	100000		
J+9	1078		
J+10	100000		
J+11	2.00		
J+12	0.10	Voltage dip threshold for FRT activation (pu)	
J+13	0.050	FRT reset time delay (s)	
J+14	1.0455		
J+15	1.00		
J+16	3.9782		
J+17	99.4544		
J+18	0.487	dKpVcon	
J+19	136.5	dKiVcon	
J+20	0.060		
J+21	1.60		
J+22	0.70		
J+23	1.20		
J+24	0.70		
J+25	1.89		
J+26	2.00		

J+27	0.82	
J+28	0.50	
J+29	0.40	
J+30	4.00	
J+31	1.23	Air density
J+32	15.00	User defined wind speed for rated power operation (m/s)
J+33	1.00	
J+34	0.1768	
J+35	0.6464	
J+36	1.0069	
J+37	13.05	
J+38	-94.25	
J+39	-52.36	
J+40	0.15	
J+41	7.0	
J+42	-8.0	
J+43	45.0	Maximum pitch angle
J+44	-1.0	Minimum pitch angle
J+45	2.0	
J+46	0.9655	
J+47	-4.73	
J+48	-0.68	
J+49	0.22	
J+50	-0.22	
J+51	1.00	
J+52	1.17	
J+53	0.90	Under Voltage Relay 1 - Voltage Setting (pu)
J+54	5.000	Under Voltage Relay 1 - Time Setting (s)
J+55	0.100	Under Voltage Relay 1 - Relay activation time (s)
J+56	0.70	Under Voltage Relay 2 - Voltage Setting (pu)
J+57	1.000	Under Voltage Relay 2 - Time Setting (s)
J+58	0.100	Under Voltage Relay 2 - Relay activation time (s)
J+59	0.15	Under Voltage Relay 3 - Voltage Setting (pu)
J+60	0.150	Under Voltage Relay 3 - Time Setting (s)
J+61	0.100	Under Voltage Relay 3 - Relay activation time (s)
J+62	1.10	Over Voltage Relay 1 - Voltage Setting (pu)
J+63	1.000	Over Voltage Relay 1 - Time Setting (s)
J+64	0.000	Over Voltage Relay 1 - Relay activation time (s)
J+65	1.20	Over Voltage Relay 2 - Voltage Setting (pu)
J+66	0.200	Over Voltage Relay 2 - Time Setting (s)
J+67	0.000	Over Voltage Relay 2 - Relay activation time (s)
J+68	0.98	Under Frequency Relay 1 - Frequency Setting (pu)
J+69	10.000	Under Frequency Relay 1 - Time Setting (s)
J+70	0.000	Under Frequency Relay 1 - Relay activation time (s)
J+71	0.97	Under Frequency Relay 2 - Frequency Setting (pu)
J+72	0.100	Under Frequency Relay 2 - Time Setting (s)
J+73	0.000	Under Frequency Relay 2 - Relay activation time (s)
J+74	1.08	Over Frequency Relay 1 - Frequency Setting (pu)
J+75	0.100	Over Frequency Relay 1 - Time Setting (s)
J+76	0.000	Over Frequency Relay 1 - Relay activation time (s)
J+77	0.15	Retained voltage threshold for Island Detection (pu)

DYRE Data (auto-generated from datasheet information. Copy/paste into DYRE file.)

/ SMK202 V1.1, 2.3 MW Turbine Data

90200 'USRMDL' 1 'SMK202' 1 1 10 78 18 53

1 1 1 1 1 1 1 1 1 1 18.0251 1.0927 14.3349 0.1458 138.49 1.3169 1.1109 22 100000 1078 100000
2.00 0.10 0.050 1.0455 1.00 3.9782 99.4544 0.487 136.5 0.060 1.60 0.70 1.20 0.70 1.89 2.00 0.82 0.50
0.40 4.00 1.23 15.00 1.00 0.1768 0.6464 1.0069 13.05 -94.25 -52.36 0.15 7.0 -8.0 45.0 -1.0 2.0 0.9655 -
4.73 -0.68
0.22 -0.22 1.00 1.17 0.90 5.000 0.100 0.70 1.000 0.100 0.15 0.150 0.100 1.10 1.000 0.000 1.20 0.200
0.000
0.98 10.000 0.000 0.97 0.100 0.000 1.08 0.100 0.000 0.15 /

APPENDIX C – STABILITY PLOTS

AVAILABLE ON REQUEST