GEN-2016-028 Impact Restudy for Generator Modification (Turbine Change)

May 2018
Generator Interconnection

Southwest Power Pool

Revision History

Date	Author	Change Description
05/08/2018	SPP	GEN-2016-028 Impact Restudy for Generator Modification (Turbine Change) issued.

Executive Summary

The GEN-2016-028 Interconnection Customer has requested a modification to its Interconnection Request. This system impact restudy was performed to determine the effects of changing wind turbine generators from the previously studied[1] 50 Vestas 2.0MW VCSS wind turbine generators (for a total of 100.0MW) to 28 Vestas 3.45MW GS and 1 Vestas 3.40MW GS wind turbine generators (for a total of 100.0MW). The point of interconnection (POI) for GEN-2016-028 is at the American Electric Power Company (AEPW) Clayton 138kV Substation.

This study was performed by Aneden Consulting to determine whether the request for modification is considered Material. The study report follows this executive summary.

The restudy showed that no stability problems were found during the summer and the winter peak conditions as a result of changing to the Vestas 3.45MW GS and Vestas 3.40MW GS wind turbine generators. Additionally, the project wind farm was found to stay connected during the contingencies that were studied and, therefore, will meet the Low Voltage Ride Through (LVRT) requirements of FERC Order #661A. The requested modification is not considered Material.

Power factor requirements for this generation facility will be in accordance with the SPP Open Access Transmission Tariff (OATT) for all newly interconnecting non-synchronous generators that have not executed a Facilities Study Agreement as of September 21, 2016. The requirements are the

> "Interconnection Customer shall design the Generating Facility to maintain a composite power delivery at continuous rated power output at the high-side of the generator substation at a power factor within the range of 0.95 leading to 0.95 lagging, unless the Transmission Provider has established a different power factor range that applies to all non-synchronous generators in the Control Area on a comparable basis. This power factor range standard shall be dynamic and can be met using, for example, power electronics designed to supply this level of reactive capability (taking into account any limitations due to voltage level, real power output, etc.) or fixed and switched capacitors, or a combination of the two. [2]"

A low-wind/no-wind condition analysis was performed for this modification request. The project will be required to install approximately 5 Mvar of reactor shunts on its substation 34.5kV bus(es). This is necessary to offset the capacitive effect on the transmission network caused by the project's transmission line and collector system during low-wind/no-wind conditions.

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[1] See DISIS-2016-001 Definitive Interconnection System Impact Study Report published on 2/28/2107 and DISIS-2016-001-1 Definitive Interconnection System Impact Study Report posted 12/22/2017

[2] SPP Open Access Transmission Tariff, Sixth Revised Volume No. 1, Attachment V, Appendix 6, Article 9.6.1.2

The dynamic stability analysis showed that for the contingencies that were simulated there were no machine rotor angle damping or transient voltage recovery violations observed in the simulated fault events. Additionally, the project wind farm was found to stay connected during the contingencies that were studied and, therefore, will meet the Low Voltage Ride Through (LVRT) requirements of FERC Order #661A.

With the assumptions outlined in this report and with all the required network upgrades from the DISIS 2016-001 in place, GEN-2016-028 with 28 Vestas 3.45MW GS and 1 Vestas 3.40MW GS wind turbine generators should be able to interconnect reliably to the SPP transmission grid.

It should be noted that this study analyzed the requested modification to change generator technology and layout. Powerflow analysis was not performed. This study analyzed many of the most probable contingencies, but it is not an all-inclusive list and cannot account for every operational situation. It is likely that the customer may be required to reduce its generation output to 0 MW, also known as curtailment, under certain system conditions to allow system operators to maintain the reliability of the transmission network.

Nothing in this study should be construed as a guarantee of transmission service or delivery rights. If the customer wishes to obtain deliverability to final customers, a separate request for transmission service must be requested on Southwest Power Pool's OASIS by the customer.

Aneden Consulting report follows.

Submitted to
Southwest Power Pool

SPP Southwest Power Pool

Report On

GEN-2016-028
Modification Request Impact Study

Revision R1

Date of Submittal
May 01, 2018

anedenconsulting.com

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Executive Summary

Aneden Consulting (Aneden) was retained by the Southwest Power Pool (SPP) to perform a Modification Request Impact Study (Study) for GEN-2016-028, an active generation interconnection request with point of interconnection (POI) at the Clayton 138 kV substation.

The GEN-2016-028 project has proposed to interconnect in the American Electric Power Company (AEPW) control area with a capacity of 100 MW including 50 Vestas V110 2.0MW wind turbines as shown in Table ES-1 below. This Study has been requested to evaluate the modification of GEN-2016-028 to 28 x Vestas V136 3.45 MW and 1 x Vestas V136 3.40 MW turbines for an unchanged 100 MW capacity. In addition, the modification request included changes to the generation interconnection line and the main substation transformer. The modification request changes are shown in Table ES-2 below.

Table ES-1: Existing GEN-2016-028 Configuration

Request	Capacity (MW)	Existing Generator Configuration	Point of Interconnection
GEN-2016-028	100	50 x Vestas V110 2.0 MW	Clayton 138 kV (510919)

Table ES-2: GEN-2016-028 Modification Request

Facility	Existing	Modification Request
Turbine Configuration	50 x Vestas V110 2.0 MW	28 x Vestas V136 3.45 MW 1 x Vestas V136 3.40 MW
Generation Interconnection Line	Length = 7 miles	Length = 4.5 miles
Main Substation Transformer	Z = 9%, Rating 115 MVA	Z = 8.5%, Rating 110 MVA
Equivalent Collector Line	R = 0.011850 pu X = 0.022269 pu B = 0.076870 pu	R =0.009996 pu X = 0.014690 pu B = 0.045610 pu

GEN-2016-028 was last studied as part of Group 14 in the DISIS-2016-001 ReStudy #1 published on December 22, 2017. Aneden performed reactive power analysis, short circuit analysis and dynamic stability analysis using the modification request data based on the ReStudy #1 study models:

1. 2016 Winter Peak (2016WP),
2. 2017 Summer Peak (2017SP) and
3. 2025 Summer Peak (2025SP).

All analyses were performed using the PTI PSS/E software and the results are summarized below.

Per SPP Tariff requirements, the Generating Facilities will be required to meet the standard 95% power factor requirement at the high side of the generator substation. This power factor range standard shall be dynamic and can be met using, for example, power electronics designed to supply this level of reactive capability (taking into account any limitations due to voltage level, real power output, etc.) or fixed and switched capacitors, or a combination of the two.

The results of the reactive power analysis, also known as the low-wind/no-wind condition analysis, performed using all three models results showed that the GEN-2016-028 project may require a 5 MVAr shunt reactor on the 138 kV bus of the project substation. The shunt reactor is needed to reduce the reactive power transfer at the POI to approximately zero during low/no wind conditions while the generation interconnection project remains connected to the grid. The ReStudy #1 showed a need for an 8.4 MVAr shunt reactor. The difference in the results can be attributed to the changes to the generation interconnection line and the collector system impedances.

The results from short circuit analysis showed that the maximum change in the fault currents in the immediate systems at or near GEN-2016-028 was 10.8%. All three-phase current levels with the GEN-2016-028 generator online was below 13,000 A.

The dynamic stability analysis was performed using the three loading scenarios 2016 Winter Peak, 2017 Summer Peak and 2025 Summer Peak simulating up to 14 faults that included three-phase, single-line-to-ground faults on prior outage cases, and stuck breakers faults. There were no machine rotor angle damping or transient voltage recovery violations observed in the simulated fault events. Additionally, the project wind farm was found to stay connected during the contingencies that were studied and, therefore, will meet the Low Voltage Ride Through (LVRT) requirements of FERC Order #661A.

The results of this Study show that the GEN-2016-28 Modification Request does not constitute a material modification.

1.0 Introduction

Aneden Consulting (Aneden) was retained by the Southwest Power Pool (SPP) to perform a Modification Request Impact Study (Study) for GEN-2016-028, an active generation interconnection request with point of interconnection (POI) at the Clayton 138 kV substation.

The GEN-2016-028 project is proposed to interconnect in the American Electric Power Company (AEPW) control area with a capacity of 100 MW including 50 Vestas V110 2.0MW wind turbines as shown in Table 1-1 below. Details of the modification request as provided in Section 2.0 below.

Table 1-1: Existing GEN-2016-028 Configuration

Request	Capacity (MW)	Existing Generator Configuration	Point of Interconnection
GEN-2016-028	100	50 x Vestas V110 2.0 MW	Clayton 138 kV (510919)

1.1 Scope

The Study included short circuit, power factor, reactive power and dynamic stabilities. The methodology, assumptions and results of the analyses are presented in the following six main sections:

1. Project and Modification Request
2. Power Factor Requirement
3. Reactive Power Analysis
4. Short Circuit Analysis
5. Dynamic Stability Analysis
6. Conclusions

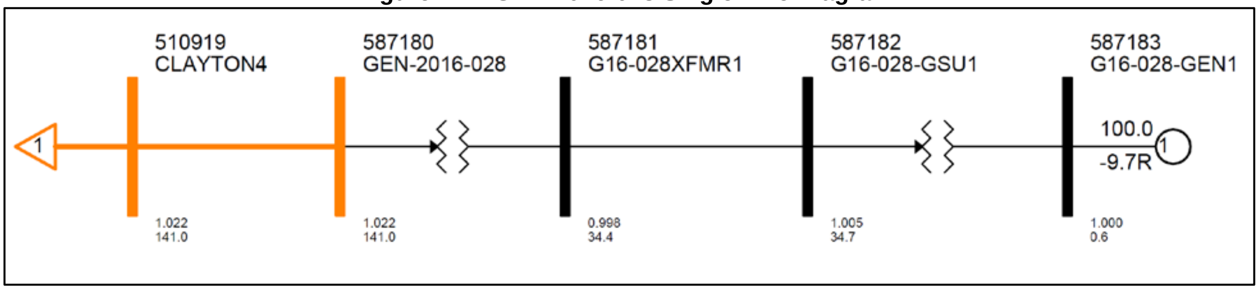
1.2 Study Limitations

The assessments and conclusions provided in this report are based on assumptions and information provided to Aneden by others. While the assumptions and information provided may be appropriate for the purposes of this report, Aneden does not guarantee that those conditions assumed will occur. In addition, Aneden did not independently verify the accuracy or completeness of the information provided. As such, the conclusions and results presented in this report may vary depending on the extent to which actual future conditions differ from the assumptions made or information used herein.

2.0 Project and Modification Request

Figure 2-1 shows the power flow model single line diagram for GEN-2016-028. GEN-2016-028 was last studied as part of Group 14 in the DISIS-2016-001 ReStudy #1 (ReStudy #1) published on December 22, 2017.

Figure 2-1: GEN-2016-028 Single Line Diagram



The GEN-2016-028 Modification Request includes the turbine change to 28 x Vestas V136 3.45 MW and 1 x Vestas V136 3.40 MW turbines for a total capacity of 100 MW. In addition, the modification request also included changes to the generation interconnection line and the main substation transformer. The major modification request changes are shown in Table 2-1 below.

Table 2-1: GEN-2016-028 Modification Request

Facility	Existing	Modification Request
Turbine Configuration	50 x Vestas V110 2.0 MW	28 x Vestas V136 3.45 MW 1 x Vestas V136 3.40 MW
Generation Interconnection Line	Length = 7 miles	Length = 4.5 miles
Main Substation Transformer	Z = 9%, Rating 115 MVA	Z = 8.5%, Rating 110 MVA
Equivalent Collector Line	R = 0.011850 pu X = 0.022269 pu B = 0.076870 pu	R =0.009996 pu X = 0.014690 pu B = 0.045610 pu

Aneden performed a reactive power analysis, short circuit analysis and dynamic stability analysis using a set of modified study models developed using the modification request data and the three ReStudy #1 study models:

1. 2016 Winter Peak (2016WP),
2. 2017 Summer Peak (2017SP), and
3. 2025 Summer Peak (2025SP).

All analyses were performed using the PTI PSS/E version 32 software.

The results of each analysis are presented in the following sections.

3.0 Power Factor Requirement

According to the SPP Open Access Transmission Tariff (OATT) for all newly interconnecting non-synchronous generators that have not executed a Facilities Study Agreement as of September 21, 2016 the:

> "Interconnection Customer shall design the Generating Facility to maintain a composite power delivery at continuous rated power output at the high-side of the generator substation at a power factor within the range of 0.95 leading to 0.95 lagging, unless the Transmission Provider has established a different power factor range that applies to all non-synchronous generators in the Control Area on a comparable basis. This power factor range standard shall be dynamic and can be met using, for example, power electronics designed to supply this level of reactive capability (taking into account any limitations due to voltage level, real power output, etc.) or fixed and switched capacitors, or a combination of the two. [1]"

[1] SPP Open Access Transmission Tariff, Sixth Revised Volume No. 1, Attachment V, Appendix 6, Article 9.6.1.2

4.0 Reactive Power Analysis

The reactive power analysis, also known as the low-wind/no-wind condition analysis, was performed for the DISIS-2016-001 (Group 14) request, GEN-2016-028 to determine the reactive power contribution from the project's interconnection line and collector transformer and cables during low/no wind conditions while the project is still connected to the grid and to size shunt reactors that would reduce the project reactive power contribution to the POI to approximately zero.

4.1 Methodology and Criteria

For the GEN-2016-028 project, the generator was switched out of service while other collector system elements remained in-service. A shunt reactor was tested at the study project substation high side bus to bring the MVAr flow into the POI down to approximately zero.

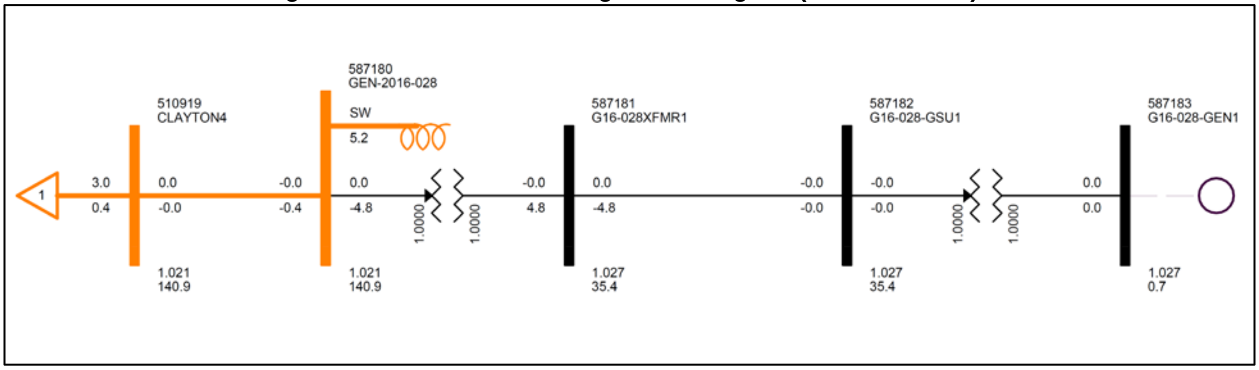
4.2 Results

The results from the reactive power analysis showed that the GEN-2016-028 project required approximately 5 MVAr shunt reactance at the high side of the project substation, to reduce the POI MVAr to zero. This represents the contributions from the project collector systems. Figure 4-1 illustrates the shunt reactor size required to reduce the POI voltage to approximately zero.

Table 4-1: Shunt Reactor Size for Low Wind Study

Machine	POI Bus Number	POI Bus Name	Reactor Size (MVAr)		
			16WP	17SP	25SP
GEN-2016-028	510919	GEN-2016-028	5	5	5

Figure 4-1: GEN-2016-028 Single Line Diagram (Shunt Reactor)*



*Reactor output varies with bus voltage. At nominal voltage, reactor outputs 5 MVAr

The shunt reactor identified in the ReStudy #1 was an 8.4 MVAr shunt reactor. The difference in the results can be attributed to the changes to the generation interconnection line and the collector system impedances.

5.0 Short Circuit Analysis

A short-circuit study was performed on the power flow models for the 2017SP and 2025SP models for GEN-2016-028 using the modified Cluster Scenario models. The detail results of the short-circuit analysis are provided in Appendix B.

5.1 Methodology

The short-circuit analysis included applying a 3-phase fault on buses up to 5 levels away from the Clayton 138 kV POI bus. The PSS/E "Automatic Sequence Fault Calculation (ASCC)" fault analysis module was used to calculate the fault current levels with and without the project online.

5.2 Results

The results of the short circuit analysis are summarized in Table 5-1 and Table 5-2 for the 2017SP and 2025SP models, respectively. The maximum increase in fault current was about 10.8%. The maximum fault current calculated within 5 buses with GEN-2016-028 was less than 13 kA.

Table 5-1: 2017SP Short Circuit Results

Number of Buses Away	Max. Change (kA)	Max %Change
0	0.406	10.8%
1	0.360	9.2%
2	0.173	2.2%
3	0.170	2.1%
4	0.160	2.0%
5	0.054	1.0%

Table 5-2: 2025SP Short Circuit Results

Number of Buses Away	Max. Change (kA)	Max %Change
0	0.402	10.7%
1	0.357	9.1%
2	0.170	2.1%
3	0.167	2.0%
4	0.157	1.9%
5	0.052	0.9%

6.0 Dynamic Stability Analysis

Aneden performed a dynamic stability analysis to identify the impact of the turbine change and other modifications to the GEN-2016-028 project. The analysis was performed according to SPP's Disturbance Performance Requirements shown in Appendix C. The modification details are described in Section 2.0 above and the dynamic modeling data is provided in Appendix D. The simulation plots can be found in Appendix E.

6.1 Methodology and Criteria

The dynamic stability analysis was performed using models developed with the requested Vestas V136 28 x 3.45 MW and 1 x 3.40 MW configuration for the GEN-2016-028 generating facility. This stability analysis was performed using PTI's PSS/E version 32 software.

The stability models were developed using the models from the DISIS-2016-001 ReStudy #1 (DISIS-2016-001-1) for Group 14. The modifications requested to project GEN-2016-028 were used to create modified stability models for this impact study.

The modified power flow models and associated dynamics database were initialized (no-fault test) to confirm that there were no errors in the initial conditions of the system and the dynamic data. The modified dynamics model data for the DISIS-2016-001-1 (Group 14) request, GEN-2016-028 is provided in Appendix D.

During the fault simulations, the active power (PELEC), reactive power (QELEC) and terminal voltage (ETERM) were monitored for GEN-2016-028 and other equally and prior queued projects in Group 14. In addition, voltages of five (5) buses away from the POI of GEN-2016-028 were monitored and plotted. The machine rotor angle for synchronous machines and speed for asynchronous machines within this study area including 520 (AEPW), 524 (OKGE), 525 (WFEC), 526 (SPS), 531 (MIDW), 534 (SUNC) and 536 (WERE) were monitored. In addition, the voltages of all 100 kV and above buses within the study area were monitored.

6.2 Fault Definitions

Aneden selected the fault events simulated specifically for GEN-2016-028 in the DISIS-2016-001 Group 14 Study and simulated those using the modified study models. The fault events include three phase faults with reclosing, stuck breaker, and prior outage events. Single-line-to-ground (SLG) fault impedance values were determined by applying a fault on the base case large enough to produce a 0.6 pu voltage value on the faulted bus. This SLG value was then used for the SLG faults.

The selected faults are listed and described in Table 6-1 below. These contingencies were applied for the modified 2016 Winter Peak, 2017 Summer Peak, and the 2025 Summer Peak models.

Table 6-1: Fault Definitions

Fault ID	Fault Description
FLT24-3PH	3 phase fault on CLAYTON4 138 kV (510919) to SARDIS 4 138 kV (510926), near CLAYTON4. a. Apply fault at the CLAYTON4 138 kV bus. b. Clear fault after 5 cycles and trip the faulted line. 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.
FLT25-3PH	3 phase fault on CLAYTON4 138 kV (510919) to NASHOBA4 138 kV (510927), near CLAYTON4. a. Apply fault at the CLAYTON4 138 kV bus. b. Clear fault after 5 cycles and trip the faulted line. 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.
FLT26-3PH	3 phase fault on SARDIS 4 138 kV (510926) to ENOWILT4 138 kV (510944), near SARDIS 4. a. Apply fault at the SARDIS 4 138 kV bus. b. Clear fault after 5 cycles and trip the faulted line. 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.
FLT27-3PH	3 phase fault on NASHOBA4 138 kV (510927) to BETHEL 4 138 kV (510928), near NASHOBA4. a. Apply fault at the NASHOBA4 138 kV bus. b. Clear fault after 5 cycles and trip the faulted line. 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.
FLT28-SB	**Stuck Breaker at LONEOAK4 (510897)** a. Apply single phase fault at LONEOAK4 bus. b. Clear fault after 16 cycles and trip the following elements c. LONEOAK4 (510897) - SMCALTP4 (510906) d. LONEOAK4 (510897) - ENOWILT4 (510944)
FLT29-SB	**Stuck Breaker at LONEOAK4 (510897)** a. Apply single phase fault at LONEOAK4 bus. b. Clear fault after 16 cycles and trip the following elements c. LONEOAK4 (510897) - HARTSHN4 (520934) d. LONEOAK4 (510897) - ENOWILT4 (510944)
FLT30-SB	**Stuck Breaker at LONEOAK4 (510897)** a. Apply single phase fault at LONEOAK4 bus. b. Clear fault after 16 cycles and trip the following elements c. LONEOAK4 (510897) - ENOWILT4 (510944) d. LONEOAK4 (510897) - CARBON 4 (520844)
FLT31-SB	**Stuck Breaker at BRKN BW4 (505614)** a. Apply single phase fault at BRKN BW4 bus. b. Clear fault after 16 cycles and trip the following elements c. BRKN BW4 (505614) - BETHEL 4 (510928) d. BRKN BW4 (505614) - CRAIGJT4 (510890)
FLT32-SB	**Stuck Breaker at BRKN BW4 (505614)** a. Apply single phase fault at BRKN BW4 bus. b. Clear fault after 16 cycles and trip the following elements c. BRKN BW4 (505614) - HOCHTWN4 (520943) d. BRKN BW4 (505614) - BETHEL 4 (510928)
FLT33-PO	**Prior Outage of LONEOAK4 (510897) to SMCALTP4 (510906) line;** 3 phase fault on LONEOAK4 (510897) – ENOWILT4 (510944) near LONEOAK4 a. Apply fault at the LONEOAK4 bus. b. Clear fault after 5 cycles and trip the faulted line.

Table 6-1 continued

Fault ID	Fault Description
FLT34-PO	**Prior Outage of LONEOAK4 (510897) to HARTSHN4 (520934) line;** 3 phase fault on LONEOAK4 (510897) – ENOWILT4 (510944) near LONEOAK4 a. Apply fault at the LONEOAK4 bus. b. Clear fault after 5 cycles and trip the faulted line.
FLT35-PO	**Prior Outage of LONEOAK4 (510897) to ENOWILT4 (510944) line;** 3 phase fault on LONEOAK4 (510897) – CARBON 4 (520844) near LONEOAK4 a. Apply fault at the LONEOAK4 bus. b. Clear fault after 5 cycles and trip the faulted line.
FLT36-PO	**Prior Outage of BRKN BW4 (505614) to BETHEL 4 (510928) line;** 3 phase fault on BRKN BW4 (505614) - CRAIGJT4 (510890) near BRKN BW4 a. Apply fault at the BRKN BW4 bus. b. Clear fault after 5 cycles and trip the faulted line.
FLT37-PO	**Prior Outage of BRKN BW4 (505614) to HOCHTWN4 (520943) line;** 3 phase fault on BRKN BW4 (505614) - BETHEL 4 (510928) near BRKN BW4 a. Apply fault at the BRKN BW4 bus. b. Clear fault after 5 cycles and trip the faulted line.

6.3 Results

Table 6-2 shows the results of the fault events simulated for each of the models. There were no damping or voltage recovery violations observed during the simulations and the system returned to stable conditions following each of the fault events. The associated stability plots are provided in Appendix E. Additionally, the project wind farm was found to stay connected during the contingencies that were studied and, therefore, will meet the Low Voltage Ride Through (LVRT) requirements of FERC Order #661A.

Table 6-2: GEN-2016-028 Dynamic Stability Results

Fault ID	2016WP	2017SP	2025SP
FLT24-3PH	Stable	Stable	Stable
FLT25-3PH	Stable	Stable	Stable
FLT26-3PH	Stable	Stable	Stable
FLT27-3PH	Stable	Stable	Stable
FLT28-SB	Stable	Stable	Stable
FLT29-SB	Stable	Stable	Stable
FLT30-SB	Stable	Stable	Stable
FLT31-SB	Stable	Stable	Stable
FLT32-SB	Stable	Stable	Stable
FLT33-PO	Stable	Stable	Stable
FLT34-PO	Stable	Stable	Stable
FLT35-PO	Stable	Stable	Stable
FLT36-PO	Stable	Stable	Stable
FLT37-PO	Stable	Stable	Stable

7.0 Conclusions

The Interconnection Customer for GEN-2016-028 requested a Modification Request Impact Study to assess the impact of the turbine and facility changes presented in Table 7-1 below.

Table 7-1: Modification Request

Facility	Existing	Modification Request
Turbine Configuration	50 x Vestas V110 2.0 MW	28 x Vestas V136 3.45 MW 1 x Vestas V136 3.40 MW
Generation Interconnection Line	Length = 7 miles	Length = 4.5 miles
Main Substation Transformer	Z = 9%, Rating 115 MVA	Z = 8.5%, Rating 110 MVA
Equivalent Collector Line	R = 0.011850 pu X = 0.022269 pu B = 0.076870 pu	R =0.009996 pu X = 0.014690 pu B = 0.045610 pu

Per SPP Tariff requirements, the Generating Facilities will be required to meet the standard 95% power factor requirement at the high side of the generator substation. This power factor range standard shall be dynamic and can be met using, for example, power electronics designed to supply this level of reactive capability (taking into account any limitations due to voltage level, real power output, etc.) or fixed and switched capacitors, or a combination of the two.

The reactive power analysis, low-wind/no-wind condition analysis, performed to determine the size of a reactor required at the GEN-2016-028 main substation during low wind conditions showed that a 5 MVAr reactor would be needed to maintain the project's reactive power contribution to the POI at zero. The ReStudy #1 showed a need for an 8.4 MVAr shunt reactor. The difference in the results can be attributed to the changes to the generation interconnection line and the collector system impedances.

The short circuit analysis showed the maximum increase in fault current caused by GEN-2016-028 did not exceed 10.8%. The largest fault current calculated was below 13 kA.

The results of the dynamic stability analysis showed that there were no machine rotor angle damping or transient voltage recovery violations observed in the simulated fault events and the system achieved stable operation after each fault event. Additionally, the project wind farm was found to stay connected during the contingencies that were studied and, therefore, will meet the Low Voltage Ride Through (LVRT) requirements of FERC Order #661A.

In conclusion, the results of this Study showed that the Modification Request shown in Table 7-1 do not constitute a material modification.