Generator Interconnection
System Impact Study Report

For

PJM Generation Interconnection Request
Queue Position #AA2-148

Madison-Tanners Creek 138 kV

September 2016

General

NextEra Energy Resources, LLC (NextEra) proposes to connect Project #AA2-148, a 175.0 MW (22.75 Capacity) wind generating facility to the American Electric Power (AEP) Transmission system at the in-line switching station proposed to be built as an attachment facility for PJM queue positions W4-004 and W4-008. The new switching station is located between Madison and Tanners Creek 138 kV substations (see Figure 1 and Figure 2). The location of the proposed wind generating facility is in Henry County, IN.

The requested in-service date is 12/31/ 2017.

The objective of this System Impact Study is to determine budgetary cost estimates and approximate construction timelines for identified transmission facilities required to connect the proposed generating facilities to the AEP Transmission System. These reinforcements include the Attachment Facilities, Local Upgrades, and Network Upgrades required to maintain the reliability of the AEP Transmission System.

Attachment Facilities

(Expanding the proposed PJM Project #W4-004 &W4-008 Switching Station)

The proposed in-line switching station identified as an attachment facility for PJM project W4-004 & W4-008 will be expanded to accommodate the interconnection of PJM project AA2-148. Two (2) additional 138 kV circuit breakers will be required. The expanded switching station will be physically arranged for ultimate expansion to a breaker and one half bus arrangement initially operated as a ring bus. The expanded station also includes the addition of the required 138 kV metering, SCADA, disconnect switches and other associated equipment.

The above attachment proposal as was outlined in the Feasibility Study report will not be able to accommodate the additional 175.0 MW generation due the stability issues identified and outlined below.

In order to accommodate the interconnection of the additional 175.0 MW generation, the proposed W4-004 & W4-008 138 kV switching station will have to be expanded. Install two (2) strings, and Six (6) additional 138 kV circuit breakers. The expanded station also includes the addition of the required 138 kV metering, SCADA, disconnect switches and other associated equipment (see Figure 1). The additional breaker string and three (3) breakers will be installed to mitigate the stability violation which is summarized below. A detailed report is included at the end of this System Impact Study in Attachment 1.

Dynamic Simulation Analysis

(See full Report in Attachment 1 at the end of this report)

It was observed when W4-004, W4-008 and AA2-148 windfarms are dispatched to full output the W4-004 TAP – Madison 138 kV line overloads at 160% of its rating (prior to

any contingencies). It was also observed that a contingency of the W4-004 TAP – Madison 138 kV line does not solve the loadflow.

For contingencies 3N.05, 1N.05 and 1D.01 (where the W4-004 TAP – Madison 138 kV line is tripped) results in W4-004 & W4-008 being tripped off on Low Voltage Ride-Through (LVRT) protection.

With AA2-148 out of service, W4-004 & W4-008 does not trip on LVRT for these contingencies.

As the low voltages leading to the W4-004 & W4-008 to trip occur after a contingency has occurred, mitigation of dynamic compensation of up to 125 MVAr was attempted.

It was found that while this did not resolve the W4-004 & W4-008 LVRT tripping, the output of the W4-004 & W4-008 units were not stable.

Reinforcements to Mitigate the Stability Issues:

Non-Direct Connection Network Upgrade

Network Upgrade Number	Description	Total Cost
n5110	Bring the Tanners Creek – Pendleton 138 kV circuit into the proposed W4-004 & W4-008 138 kV switching station which will require adding an additional string and three (3) new 138 kV circuit breakers (see figure 1). Associated disconnect switches, bus work, SCADA and 138 kV revenue metering will also be required.	$3,450,000
	Total	**$3,450,000**

Station Cost:

Direct Connection Network Upgrade

Network Upgrade Number	Description	Total Cost
n5109	Expand the proposed in-line switching station identified as an attachment facility for PJM project W4-004 & W4-008. Add three (3) 138 kV circuit breakers (see Figure 1). The expanded switching station will have a configuration of a breaker and one half bus arrangement. Associated disconnect switches, bus work, SCADA and 138 kV revenue metering will also be required.	$3,450,000
	Total	**$3,450,000**

- **Estimated Total Station Expansion Cost: $6,900,000**

Protection and Relaying Costs:

Non-Direct Connection Network Upgrades

Network Upgrade Number	Description	Total Cost
n5111	Line protection and controls will need to be installed at the newly expanded 138 kV switching station. Estimated Cost	$250,000
n5112	Update relay settings at Madison 138 kV station. Estimated Cost	$50,000
n5113	Update relay settings at Tanners Creek 138 kV station. Estimated Cost	$50,000
n5114	Update line protection and controls at Pendleton 138 kV station	$200,000
	Total	**$550,000**

It is understood that NextEra is responsible for all these connection costs associated with interconnecting the PJM project #AA2-148 to AEP transmission system. The costs above are reimbursable to AEP. The cost of NextEra's generating plant and the costs for the line connecting the generating plant to NextEra's switching station are not included in this report; these are assumed to be NextEra's responsibility.

The Generation Interconnection Agreement does not in or by itself establish a requirement for American Electric Power to provide power for consumption at the developer's facilities. A separate agreement may be reached with the local utility that provides service in the area to ensure that infrastructure is in place to meet this demand and proper metering equipment is installed. It is the responsibility of the developer to contact the local service provider utility to determine if a local service agreement is required.

Local and Network Impacts

The impact of the proposed wind generating facility on the AEP System was assessed for adherence with applicable reliability criteria. AEP planning criteria require that the transmission system meet performance parameters prescribed in the AEP FERC Form 715[1] and Connection Requirements for AEP Transmission System[2]. Therefore, these criteria were used to assess the impact of the proposed facility on the AEP System. The Queue Project AA2-148 was evaluated as a 175.0 MW (Capacity 22.8 MW) injection into the W4-004/W4-008 138 kV substation (tap of the Madison – Tanners Creek 138 kV line) in the AEP area. Project AA2-148 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AA2-148 was studied with a commercial probability of 100%.

Potential network impacts were as follows:

Summer Peak Analysis - 2019

Generator Deliverability
(Single or N-1 contingencies for the Capacity portion only of the interconnection)

None

Multiple Facility Contingency

1 https://www.aep.com/about/codeofconduct/OASIS/TransmissionStudies/GuideLines/AEP_East_FERC_715_2016_Final_Part_4.pdf

2 https://www.aep.com/about/codeofconduct/OASIS/TransmissionStudies/Requirements/AEP_Interconnection_Requirements_rev1.pdf

(Double Circuit Tower Line, Fault with a Stuck Breaker, and Bus Fault contingencies for the full energy output)

None

Contribution to Previously Identified Overloads

(This project contributes to the following contingency overloads, i.e. "Network Impacts", identified for earlier generation or transmission interconnection projects in the PJM Queue)

AA2-148 Contributions to Previously Identified Overloads														
		Contingency			Bus				Loading		Rating			
#	Type	Name	Affected Area	Facility Description	From	To			Initial	Final	Type	MVA		Appendix
1	LFFB	2965_C2_05 DESOTO 345-A2	AEP - AEP	05HOGAN-05DELAWR 138 kV line	243311	243275	1	AC	114.7	121.58	ER	179	14.51	1

Short Circuit

(Summary of impacted circuit breakers)

None

Stability Analysis

See Attachment 1 at the end of this report

Voltage Variations

None

Delivery of Energy Portion of Interconnection Request

PJM also studied the delivery of the energy portion of this interconnection request. Any problems identified below are likely to result in operational restrictions to the project under study. The developer can proceed with network upgrades to eliminate the operational restriction at their discretion by submitting a Merchant Transmission Interconnection request.

Only the most severely overloaded conditions are listed. There is no guarantee of full delivery of energy for this project by fixing only the conditions listed in this section. With a Transmission Interconnection Request, a subsequent analysis will be performed, which will study all overload conditions associated with the overloaded element(s) identified.

AA2-148 The Queue Project AA2-148 Delivery of Energy Portion of Interconnection Request												
#	Type	Name	Contingency Affected Area	Facility Description	Bus From	Bus To	Cir.	Loading Initial	Loading Final	Rating Type	Rating MVA	MW Con.
1	N-1	4817_B2_TOR6341	AEP - AEP	05DESOTO-05SORENS 345 kV line	243218	243232	2	102.33	104.58	NR	971	22.61
2	N-1	8702_B2_TOR2543	AEP - AEP	05KEYSTN-05SORENS 345 kV line	243225	243232	1	127.69	130.1	NR	897	22.31
3	N-1	674_B3_05DESOTO 345-1_WOMOP	AEP - AEP	05HOGAN-05DELAWR 138 kV line	243311	243275	1	106.32	112.92	ER	179	12.97
4	Non	Non	AEP - AEP	05HOGAN-05DELAWR 138 kV line	243311	243275	1	93.05	103.17	NR	138	16.27
5	N-1	8181_B2_TOR13901756	AEP - AEP	W4-004 C-05MADISO 138 kV line	247588	243333	1	78.81	160.79	ER	223	174.98
6	Non	Non	AEP - AEP	W4-004 C-05MADISO 138 kV line	247588	243333	1	77.67	137.33	NR	191	116.18
7	N-1	8182_B2_TOR14001756	AEP - AEP	W4-004 C-05TANNER 138 kV line	247588	243382	1	87.61	172.96	ER	205	174.98
8	N-1	349_B2_TOR21	OVEC - AEP	06KYGER-05SPORN 345 kV line	248005	242528	2	108.52	109.72	NR	971	13.64

Light Load Analysis - 2019

Light Load violations and appropriate mitigations will be determined in the Facilities Study

Additional Limitations of Concern

- Numerous overloads were identified in the delivery of energy portion of the study that don't require mitigation per the PJM tariff, but may subject the AA2-148 project to curtailment in actual operation.

Local/Network Upgrades

- To relieve the overload on the 05HOGAN-05DELAWR 138 kV line: There is a planned supplemental upgrade (S0738 - Upgrade the Delaware - Hogan 138 kV risers) presently planned to be put into service by summer 2019. The present projected in-service date of S0738 is 12/31/18. The planned summer 2019 ratings should be 167/238 MVA SN/SE. These ratings are sufficient for AA2-148.

Schedule

It is anticipated that the time between receipt of executed agreements and Commercial Operation may range from 18 to 24 months if no line work is required. If line work is required, construction time would be between 36 to 48 months after signing an interconnection agreement.

Conclusion

Based upon the results of this System Impact Study, the construction of the 175.0 MW (22.75 MW Capacity) wind generating facility of NextEra (PJM Project #AA2-148) will require the following additional interconnection charges. This plan of service will interconnect the proposed wind generating facility in a manner that will provide operational reliability and flexibility to both the AEP system and the NextEra generating facility.

Estimated Cost to connect project AA2-148 to the proposed W4-004 & W4-008 138 kV switching station: $6,900,000
Estimated Protection and Relaying Cost: $550,000
Total Estimated Cost for Project AA2-148: $7,450,000

These estimates are preliminary in nature, as they were determined without the benefit of detailed engineering studies. Final estimates will require an on-site review and coordination to determine final construction requirements.

Figure 1: Point of Interconnection (Expand the W4-004 & W4-008 138 kV Switching Station) Single-Line Diagram

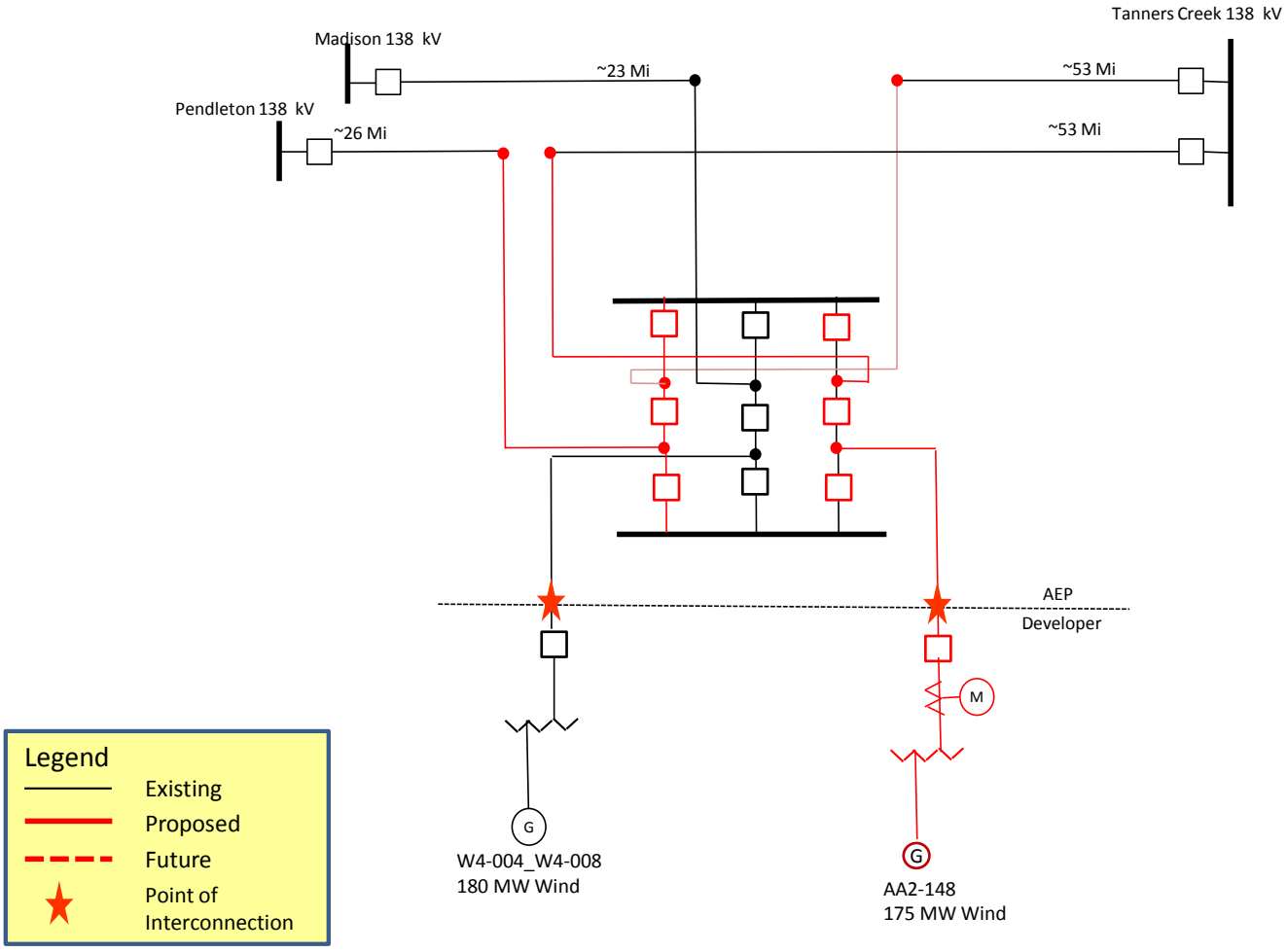

Figure 2: Point of Interconnection (Expand the W4-004 & W4-008 138 kV Switching Station)

Attachment 1 - Stability and Reactive Power Requirements

Executive Summary

Generator Interconnection Request AA2-148 is for a 175 MW Maximum Facility Output (MFO) wind powered facility consisting of 98 x GE 1.79 MW wind turbines. AA2-148 has a Point of Interconnection (POI) at the W4-004/W4-008 tap of the Madison – Tanners Creek 138 kV circuit in the American Electric Power (AEP) transmission system, Fayette County, Indiana.

This report describes a dynamic simulation analysis of AA2-148 as part of the overall system impact study.

The load flow scenario for the analysis was based on the RTEP 2019 summer peak case, modified to include applicable queue projects. AA2-148 has been dispatched online at maximum power output, with approximately unity power factor and 1.0 pu voltage at the generator bus.

AA2-148 was tested for compliance with NERC, PJM, Transmission Owner and other applicable criteria. 68 contingencies were studied, each with a 10 second simulation time period. Studied faults included:

a) Steady state operation (20 second simulation)

b) Three phase faults with normal clearing time

c) Single phase faults with stuck breaker

d) Single phase faults with delayed (Zone 2) clearing at remote end due to primary relaying failure.

e) Single phase faults with loss of multiple-circuit tower line

No relevant bus contingencies were identified.

For all simulations, the queue project under study along with the rest of the PJM system were required to maintain synchronism and with all states returning to an acceptable new condition following the disturbance.

It was observed when W4-004 & W4-008 and AA2-148 windfarms are dispatched to full output the W4-004 TAP – Madison 138 kV line overloads at 160% of its rating (prior to any contingencies). It was also observed that a contingency of the W4-004 TAP – Madison 138 kV line does not solve in loadflow.

For contingencies 3N.05, 1B.05 and 1D.01 (where the W4-004 TAP – Madison 138 kV line is tripped) results in W4-004 & W4-008 being tripped off on Low Voltage Ride-Through (LVRT) protection.

With AA2-148 out of service, W4-004 & W4-008 does not trip on LVRT for these contingencies.

As the low voltages leading to the W4-004 & W4-008 to trip occur after a contingency has
occurred, mitigation of dynamic compensation of up to 125 MVAr was attempted.

It was found that while this did resolve the W4-004 & W4-008 LVRT tripping, the output of the W4-004 & W4-008 units were not stable.

Reinforcements to Mitigate the Stability Issues

Bring the Tanners Creek – Pendleton 138 kV circuit into the proposed W4-004 & W4-008 138 kV switching station which will require adding two (2) additional strings and six (6) new 138 kV circuit breakers (see figure 1).

Results with the Upgrade modeled

Contingency 1T.05 shows W4-004/008 PELEC taking a long time (9 sec) to return to full output due to low post-contingent terminal voltages (approximately 0.9pu). The contingency was re-run to 20 seconds and the results indicate the PELEC result is stable. With the queue project AA2-148 switched off the W4-004/008 terminal voltage is higher and the W4-004/008 PELEC returns to full output more quickly, indicating that AA2-148 contributes towards the behavior observed.

All 68 contingencies met the recovery criteria:

a) Post-contingency oscillations were positively damped with a damping margin of at least 3%.

b) The AA2-148 generator was able to ride through all faults (except for faults where protective action trips a generator(s)).

1. Introduction

Generator Interconnection Request AA2-148 is for a 175 MW Maximum Facility Output (MFO) wind powered facility consisting of 98 x GE 1.79 MW wind turbines. AA2-148 has a Point of Interconnection (POI) at a tap of the Madison – Tanners Creek 138 kV circuit in the American Electric Power (AEP) transmission system, Fayette County, Indiana.

This analysis is effectively a screening study to determine whether the addition of AA2-148 will meet the dynamic requirements of the NERC, PJM and Transmission Owner reliability standards.

In this report the AA2-148 project and how it is proposed to be connected to the grid are first described, followed by a description of how the project is modeled in this study. The fault cases are then described and analyzed, and lastly a discussion of the results is provided.

2. Description of Project

AA2-148 consists of 98 x 1.79 MW GE wind turbines. AA2-148 will be connected to the POI via a 138/34.5/13.8 kV main collector transformer with a rating of 114/152/190 MVA (OA/F1/F2) and a 34.5/0.69 kV generator step up (GSU) transformer with a rating of 196 MVA (OA). The AA2-148 POI will be at a tap of the Madison – Tanners Creek 138 kV circuit as shown in Figure 1.
Table 1 lists the parameters given in the impact study data and the corresponding parameters of the AA2-148 loadflow model.
The dynamic models for the AA2-148 plant are based on standard PSS/E models, with parameters supplied by the Developer.
Additional project details are provided in Attachments 1 through 4:

- Attachment 1 contains the Impact Study Data which details the proposed AA2-148 project.
- Attachment 2 shows the one line diagram of the DVP network in the vicinity of AA2-148.
- Attachment 3 provides a diagram of the PSS/E model in the vicinity of AA2-148.
- Attachment 4 gives the AA2-148 PSS/E loadflow and dynamic models of the AA2-148 plant.

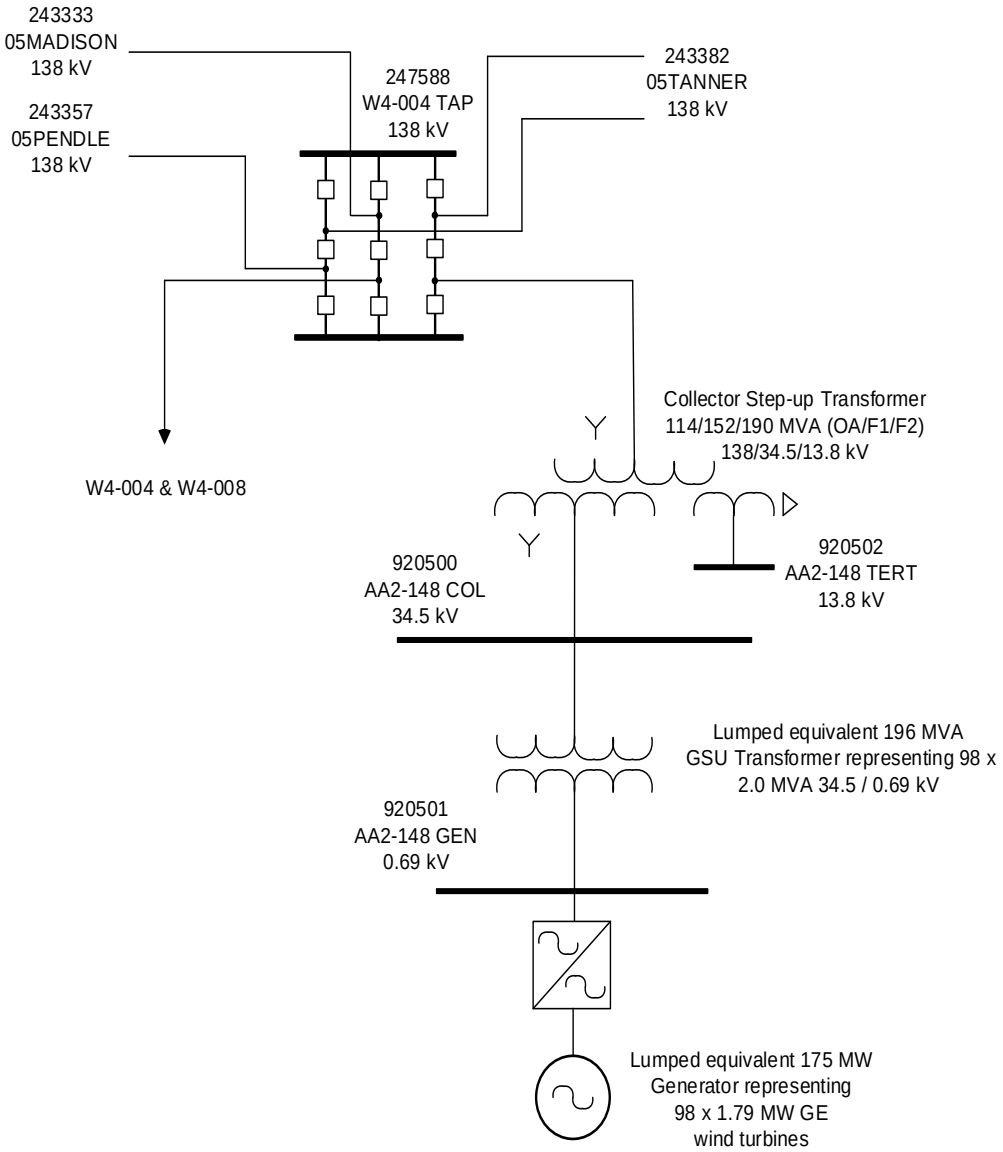

Figure 1: AA2-148 Plant Model

Table 1: AA2-148 Plant Model

	Impact Study Data	Model
GE wind turbine generators	98 x GE 1.79 MW wind turbine generators MVA base = 1.828 MVA Vt = 0.69 kV Unsaturated sub-transient reactance = j0.8 pu @ MVA base	Lumped equivalent representing 98 x 1.79 GE wind turbine generators Pgen 175 MW Pmax 175 MW Pmin 0 MW Qgen 0 MVAr Qmax 58 MVAr Qmin -58 MVAr Mbase 179.14 MVA Zsorce j0.8 pu @ Mbase
GE wind turbine GSU transformers	98 x 34.5/0.69 kV transformers Rating = 2 MVA (OA) Transformer base = 2 MVA Impedance = 0.7132 + 5.7 % @ MVA Base Number of taps = Not Given Tap step size = Not Given	Lumped equivalent representing 98 x 2 MVA GSU transformers Rating = 196 MVA Transformer base = 196 MVA Impedance = 0.007132 + 0.057 @ MVA Base Number of taps = 5 Tap step size = 2.5 %
Collector transformer	138.0/34.5/13.8 kV transformer Rating = 114/152/190 MVA (OA/F1/F2) Transformer base = 114 MVA Impedances HV – LV = 0.2124 + 8.5 % HV – Tert = 0.175 + 14 % LV – Tert = 0.25 + 5 % @ MVA Base Number of taps = 5 Tap step size = 0. 25%	138.0/34.5/13.8 kV transformer Rating = 114/152/190 MVA Transformer base = 114 MVA Impedances HV – LV = 0.002124 + 0.085 HV – Tert = 0.00175 + 0.14 LV – Tert = 0.0025 + 0.05 pu @ MVA Base Number of taps = 5 Tap step size = 0.25%
Auxiliary load	0.8 MW + 0.2 MVAR	Not modeled
Station load	0.075 MW + 0.02 MVAR	Not modeled
Transmission line	N/A	N/A

3. Loadflow and Dynamics Case Setup

The dynamics simulation analysis was carried out using PSS/E Version 32.2.4.
The load flow scenario and fault cases for this study are based on PJM's Regional Transmission Planning Process[3].
The selected load flow scenario is the RTEP 2019 summer peak case with the following modifications:

a) Addition of all applicable queue projects prior to AA2-148.

b) Addition of AA2-148 queue project.

c) Removal of withdrawn and subsequent queue projects in the vicinity of AA2-148.

d) Dispatch of units in the PJM system to maintain slack generators within limits.

The AA2-148 initial conditions are listed in Table 2, indicating maximum power output, with unity power factor and approximately 1.0 pu voltage at the generator bus.

Table 2: AA2-148 machine initial conditions

Bus	Name	Unit	PGEN	QGEN	ETERM	POI Voltage
920501	AA2-148 GEN	1	175 MW	0 MVAr	1.000 pu	1.008 pu

Generation within the PJM500 system (area 225 in the PSS/E case) and within the vicinity of AA2-148 has been dispatched online at maximum output (PMAX). The dispatch of generation in the vicinity of AA2-148 is given in Attachment 5.

[3] Manual 14B: PJM Region Transmission Planning Process, Rev 33, May 5 2016, Attachment G : PJM Stability, Short Circuit, and Special RTEP Practices and Procedures.

4. Fault Cases

Tables 4 to 8 list the contingencies that were studied, with representative worst case total clearing times provided by PJM. Each contingency was studied over a 10 second simulation time interval.
The studied contingencies include:

a) Steady state operation (20 second simulation);

b) Three-phase faults with normal clearing time;

c) Single-phase faults with phase delayed clearing due to a stuck breaker;

d) Single-phase faults placed at 80% of the line with delayed (Zone 2) clearing at line end remote from fault due to primary communications/relay failure.

e) Single-phase faults with loss of multiple-circuit tower line;

No relevant bus contingencies were identified.
The contingencies listed above were applied to:

- W4-004/008 TAP 138 kV (AA2-148 POI)
- Madison 138 kV
- Tanners Creek 138 kV
- Tanners Creek 345 kV
- U2-090 345 kV
- Pendleton 138 kV

Additional delayed (Zone 2) clearing at remote and faults will be applied on lines from College Corner 138 kV, Dearborn 345 kV, Desoto 345 kV, V4-033 345 kV, Miami Fort 345 kV, East Bend 345 kV, Hanna 345 kV, V4-033 345 kV, Fall Creek 138 kV and Strawton 138 kV towards the queue project.
Clearing times listed are as per revision 18 of "*2016 Revised Clearing times for each PJM company*" spreadsheet.
Attachment 2 contains the one-line diagrams of the AEP network in the vicinity of AA2-148, showing where faults were applied.
The positive sequence fault impedances for single line to ground faults were derived from a separate short circuit case, modified to ensure that connected generators in the vicinity of AA2-148 have not withdrawn from the PJM queue, and are not greater than the queue position under study.

5. Evaluation Criteria

This study is focused on AA2-148, along with the rest of the PJM system, maintaining synchronism and having all states return to an acceptable new condition following the disturbance. The recovery criteria applicable to this study are as per PJM's Regional Transmission Planning Process and Transmission Owner criteria:

a) The system with AA2-148 included is transiently stable and post-contingency oscillations should be positively damped with a damping margin of at least 3%.

b) AA2-148 is able to ride through faults (except for faults where protective action trips a generator(s)).

c) Following fault clearing, all bus voltages recover to a minimum of 0.7 per unit after 2.5 seconds (except where protective action isolates that bus).

d) No transmission element trips, other than those either directly connected or designed to trip as a consequence of that fault.

6. Summary of Results

Plots from the dynamic simulations are provided in Attachment 6 with results summarized in Table 3 through Table 7.
It was observed when W4-004 & W4-008 and AA2-148 windfarms are dispatched to full output the W4-004 TAP – Madison 138 kV line overloads at 160% of its rating (prior to any contingencies). It was also observed that a contingency of the W4-004 TAP – Madison 138 kV line does not solve in loadflow.

For contingencies 3N.05, 1B.05 and 1D.01 (where the W4-004 TAP – Madison 138 kV line is tripped) results in W4-004 & W4-008 being tripped off on Low Voltage Ride-Through (LVRT) protection.

With AA2-148 out of service, W4-004 & W4-008 does not trip on LVRT for these contingencies.

As the low voltages leading to the W4-004 & W4-008 to trip occur after a contingency has
occurred, mitigation of dynamic compensation of up to 125 MVAr was attempted.

It was found that while this did resolve the W4-004 & W4-008 LVRT tripping, the output of
the W4-004 & W4-008 units were not stable.

Reinforcements to Mitigate the Stability Issues
Bring the Tanners Creek – Pendleton 138 kV circuit into the proposed W4-004 & W4-008 138 kV switching station which will require adding two (2) additional strings and six (6) new 138 kV circuit breakers (see figure 1).

Results with the Upgrade modeled
Contingency 1T.05 shows W4-004/008 PELEC taking a long time to return to full output due to low post-contingent terminal voltages (approximately 0.9pu). The contingency was re-run to 20 seconds and the results indicate the PELEC result is stable. With the queue project AA2-148 switched off the W4-004/008 terminal voltage is higher and the W4-004/008 PELEC returns to full output more quickly, indicating that AA2-148 contributes towards the behavior observed.
The 68 fault contingencies tested on the 2019 summer peak case met the recovery criteria:

a) Post-contingency oscillations were positively damped with a damping margin of at least 3%.

b) AA2-148 generator was able to ride through all faults (except for faults where protective action trips a generator(s)).

c) Following fault clearing, all bus voltages recover to a minimum of 0.7 per unit after 2.5 seconds (except where protective action isolates that bus).

d) No transmission element trips, other than those either directly connected or designed to trip as a consequence of that fault.

The following work is required to connect Project AA2-148 to the proposed W4-004 & W4-008 138 kV switching station as a result of the of the stability study:

Station Cost:

- Expand the proposed in-line switching station identified as an attachment facility for PJM project #W4-004/-008. Add six (6) 138 kV circuit breakers (see Figure 1). The expanded switching station will have a configuration of a breaker and one half bus arrangement. Associated disconnect switches, bus work, SCADA and 138 kV revenue metering will also be required.
- **Estimated Station Cost: $6,900,000**

Protection and Relaying Cost:

- Line protection and controls will need to be installed at the newly expanded 138 kV switching station. Estimated Cost: $250,000
- Update relay settings at Madison 138 kV station. Estimated Cost: $50,000
- Update relay settings at Tanners Creek 138 kV station. Estimated Cost: $50,000
- Update line protection and controls at Pendleton 138 kV station. Estimated Cost: $200,000
- **Total Estimated Protection and Relaying Cost: $550,000**

Table 3: Steady State Operation

Fault ID	Duration	AA2-148 With Mitigation
SS.01	Steady state 20 sec	Stable

Table 4: Three-phase Faults With Normal Clearing

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AA2-148 With Mitigation
3N.01	Fault at W4-004/W4-008/AA2-148 138 kV POI on AA2-148 circuit (trips AA2-148).	5.5	Stable
3N.02	Fault at W4-004/W4-008/AA2-148 138 kV POI on W4-004/W4-008 circuit (trips W4-004/W4-008).	5.5	Stable
3N.03	Fault at W4-004/W4-008/AA2-148 138 kV POI on Madison circuit.	5.5	Stable
3N.04	Fault at W4-004/W4-008 Tap 138 kV POI on Tanners Creek circuit 1.	5.5	Stable
3N.05	Fault at W4-004/W4-008 Tap 138 kV POI on Tanners Creek circuit 2.	5.5	Stable
3N.06	Fault at W4-004/W4-008 Tap 138 kV POI on Pendleton circuit.	5.5	Stable
3N.07	Fault at Madison 138 kV on W4-004/W4-008/AA2-148 (Tanners Creek) circuit.	5.5	Stable
3N.08	Fault at Madison 138 kV on Delco Remy 5 circuit.	5.5	Stable
3N.09	Fault at Madison 138 kV on Fall Creek circuit.	5.5	Stable
3N.10	Fault at Madison 138 kV on Daleville – Medford – Desoto circuit.	5.5	Stable
3N.11	Fault at Madison 138 kV on Meadowbrook – Pendleton circuit.	5.5	Stable
3N.12	Fault at Madison 138 kV on Cross Street Tap – Arnold Hogan circuit.	5.5	Stable
3N.13	Fault at Tanners Creek 138 kV on W4-004/W4-008/AA2-148 circuit 1.	5.5	Stable
3N.14	Fault at Tanners Creek 138 kV on W4-004/W4-008/AA2-148 circuit 2.	5.5	Stable
3N.15	DELETED AS TANNERS CREEK IS DEACTIVATED	5.5	Stable
3N.16	DELETED AS TANNERS CREEK IS DEACTIVATED	5.5	Stable
3N.17	Fault at Tanners Creek 138 kV on Drewersburg – College Corner circuit 1.	5.5	Stable
3N.18	Fault at Tanners Creek 138 kV on Wesley switch – College Corner circuit 2.	5.5	Stable
3N.19	Fault at Tanners Creek 138 kV on 138 kV / 345 kV Transformer T-5.	5.5	Stable
3N.20	Fault at Pendleton 138 kV on W4-004/W4-008/AA2-148 circuit.	5.5	Stable
3N.21	Fault at Pendleton 138 kV on Falls Creek circuit.	5.5	Stable

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AA2-148 With Mitigation
3N.22	Fault at Pendleton 138 kV on Rose Hill – Linwood – South Elwood Tap Sw. – Strawton circuit.	5.5	Stable
3N.23	Fault at Pendleton 138 kV on Pendleton 138 kV / 34 kV Transformer 2.	5.5	Stable
3N.24	Fault at Pendleton 138 kV on Meadowbrook – Madison circuit.	5.5	Stable

Table 5: Single-phase Faults with Stuck Breaker

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AA2-148 With Mitigation
1B.01	Fault at W4-004/W4-008/AA2-148 138 kV POI on AA2-148 circuit (trips AA2-148). Center breaker stuck. Fault cleared with loss of Tanners Creek circuit.	5.5 / 16	Stable
1B.02	Fault at W4-004/W4-008/AA2-148 138 kV POI on W4-004 circuit (trips W4-004/W4-008). Center breaker stuck. Fault cleared with loss of Madison circuit.	5.5 / 16	Stable*
1B.03	Fault at W4-004/W4-008/AA2-148 138 kV POI on Madison circuit. Center breaker stuck. Fault cleared with loss of W4-004/008 (Trips W4-004/008).	5.5 / 16	Stable*
1B.04	Fault at W4-004/W4-008/AA2-148 138 kV POI on Tanners Creek circuit 1. Center breaker stuck. Fault cleared with loss of Pendleton circuit.	5.5 / 16	Stable
1B.05	Fault at W4-004/W4-008/AA2-148 138 kV POI on Tanners Creek circuit 2. Center breaker stuck. Fault cleared with loss of AA2-148 circuit (Trips AA2-148).	5.5 / 16	Stable
1B.06	Fault at W4-004/W4-008 Tap 138 kV on Pendleton circuit. Center breaker stuck. Fault cleared with loss of Tanners Creek circuit 1.	5.5 / 16	Stable
1B.07	Fault at Madison 138 kV on W4-004/W4-008/AA2-148 (Tanners Creek) circuit. Breaker U stuck. Fault cleared with loss of Daleville – Desoto circuit and Delco Remy 5 circuit.	5.5 / 16	Stable
1B.08	Fault at Madison 138 kV on Delco Remy 5 circuit. Breaker Y stuck. Fault cleared with loss of W4-004/W4-008/AA2-148 circuit and Daleville – Desoto circuit.	5.5 / 16	Stable
1B.09	Fault at Madison 138 kV on Fall Creek circuit. Breaker T stuck. Fault cleared with loss of Cross Street Tap – Arnold Hogan circuit, Meadowbrook – Pendleton circuit and Madison 138 kV / 34 kV Transformer 1.	5.5 / 16	Stable
1B.10	Fault at Madison 138 kV on Daleville – Desoto circuit. Breaker N stuck. Fault cleared with loss of W4-004/W4-008/AA2-148 (Tanners Creek) circuit and Delco Remy 5 circuit.	5.5 / 16	Stable
1B.11	Fault at Madison 138 kV on Meadowbrook – Pendleton circuit. Breaker X stuck. Fault cleared with loss of Cross Street Tap – Arnold Hogan circuit, Fall Creek circuit and Madison 138 kV / 34 kV Transformer 1.	5.5 / 16	Stable
1B.12	Fault at Tanners Creek 138 kV on W4-004/W4-008/AA2-148 circuit 1. Breaker B stuck. Fault cleared with loss of Wesley Switch – College Corner circuit 2.	5.5 / 16	Stable
1B.13	Fault at Tanners Creek 138 kV on W4-004/W4-008/AA2-148 circuit 2. Breaker A stuck. Fault cleared with loss of Drewersburg – College Corner circuit 1.	5.5 / 16	Stable
1B.14	DELETED AS TANNERS CREEK IS DEACTIVATED	5.5 / 16	Stable
1B.15	DELETED AS TANNERS CREEK IS DEACTIVATED	5.5 / 16	Stable

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AA2-148 With Mitigation
1B.16	DELETED AS TANNERS CREEK IS DEACTIVATED	5.5 / 16	Stable
1B.17	DELETED AS TANNERS CREEK IS DEACTIVATED	5.5 / 16	Stable
1B.18	Fault at Tanners Creek 138 kV on Drewersburg – College Corner circuit 1. Breaker C stuck. Fault cleared with loss of Pendleton circuit.	5.5 / 16	Stable
1B.19	Fault at Tanners Creek 138 kV on Wesley switch – College Corner circuit 2. Breaker D stuck. Fault cleared with loss of W4-004/W4-008/AA2-148 (Madison) circuit.	5.5 / 16	Stable
1B.20	Fault at Tanners Creek 138 kV on 345 kV / 138 kV transformer T-5. Breaker J stuck. Fault cleared with loss of Wesley Switch – College Corner circuit 2 and W4-004/W4-008/AA2-148 (Madison) circuit.	5.5 / 16	Stable
1B.21	Fault at Tanners Creek 138 kV on 345 kV / 138 kV transformer T-5. Breaker K stuck. Fault cleared with loss of Drewersburg – College Corner circuit 1 and Pendleton circuit.	5.5 / 16	Stable
1B.22	Fault at Pendleton 138 kV on W4-004/W4-008/AA2-148 circuit. Breaker B stuck. Fault cleared with loss of Meadowbrook – Madison circuit.	5.5 / 16	Stable
1B.23	Fault at Pendleton 138 kV on Falls Creek circuit. Breaker M stuck. Fault cleared with loss of Rose Hill – Linwood – South Elwood Tap Sw. circuit and Pendleton 138 kV / 34 kV Transformer 2.	5.5 / 16	Stable
1B.24	Fault at Pendleton 138 kV on Rose Hill – Linwood – South Elwood Tap Sw. – Strawton circuit. Breaker A stuck. Fault cleared with loss of Fall creek circuit and Pendleton 138 kV / 34 kV Transformer 2.	5.5 / 16	Stable
1B.25	Fault at Pendleton 138 kV on Meadowbrook – Madison circuit. Breaker N stuck. Fault cleared with loss of W4-004/W4-008/AA2-148 circuit.	5.5 / 16	Stable

*Plots show W4-004_008 GEN PELEC at non-zero value after the unit was tripped from protective action. P and Q flows were checked on the nearest branch to W4-004 to confirmed the cause of the non-zero value is due to the reporting of the W4-004_008 dynamic model.

Table 6: Single-phase Faults With Delayed (Zone 2) Clearing at Remote End

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AA2-148 With Mitigation
1D.01	Fault at 80% of 138 kV line from W4-004/W4-008/AA2-148 138 kV POI to Madison. Delayed clearing at W4-004/W4-008/AA2-148.	5.5 / 60	Stable
1D.02	Fault at 80% of 138 kV line from W4-004/W4-008/AA2-148 138 kV POI to Tanners Creek circuit 1. Delayed clearing at W4-004/W4-008/AA2-148.	5.5 / 60	Stable
1D.03	Fault at 80% of 138 kV line from W4-004/W4-008/AA2-148 138 kV POI to Tanners Creek circuit 2. Delayed clearing at W4-004/W4-008/AA2-148.	4.5 / 60	Stable
1D.04	Fault at 80% of 138 kV line from W4-004/W4-008/AA2-148 138 kV POI to Pendleton circuit. Delayed clearing at W4-004/W4-008/AA2-148.	4.5 / 60	Stable
1D.05	Fault at 80% of 138 kV line from Madison 138 kV to (Cross Street Tap) Arnold Hogan. Delayed clearing at Madison.	5.5 / 60	Stable
1D.06	Fault at 80% of 138 kV line from Madison 138 kV to (Daleville) Desoto. Delayed clearing at Madison.	5.5 / 60	Stable
1D.07	Fault at 80% of 138 kV line from Madison 138 kV to Fall Creek. Delayed clearing at Madison.	5.5 / 60	Stable
1D.08	Fault at 80% of 138 kV line from Madison 138 kV to Delco Remy 5. Delayed clearing at Madison.	5.5 / 60	Stable
1D.09	Fault at 80% of 138 kV line from Madison 138 kV to (Meadowbrook) Pendleton. Delayed clearing at Madison.	5.5 / 60	Stable
1D.10	Fault at 80% of 138 kV line from Tanners Creek 138 kV to (Drewersburg) College Corner on circuit 1. Delayed clearing at Tanners Creek.	5.5 / 60	Stable
1D.11	Fault at 80% of 138 kV line from Tanners Creek 138 kV to (Wesley Switch) College Corner on circuit 2. Delayed clearing at Tanners Creek.	5.5 / 60	Stable
1D.12	Fault at 80% of line from Tanners Creek 345 kV to Dearborn. Delayed clearing at Tanners Creek.	4.5 / 60	Stable
1D.13	Fault at 80% of line from Tanners Creek 345 kV to Desoto on circuit no. 1. Delayed clearing at Tanners Creek.	4.5 / 60	Stable
1D.14	Fault at 80% of line from Tanners Creek 345 kV to V4-033 (Desoto) on circuit no. 2. Delayed clearing at Tanners Creek.	4.5 / 60	Stable
1D.15	Fault at 80% of line from Tanners Creek 345 kV to Miami Fort. Delayed clearing at Tanners Creek.	4.5 / 60	Stable
1D.16	Fault at 80% of line from Tanners Creek 345 kV to East Bend. Delayed clearing at Tanners Creek.	4.5 / 60	Stable
1D.17	Fault at 80% of line from Pendleton 138 kV to Fall Creek. Delayed clearing at Pendleton.	4.5 / 60	Stable
1D.18	Fault at 80% of line from Pendleton 138 kV to Rose Hill – Linwood – South Elwood Tap Sw. – Strawton circuit. Delayed clearing at Pendleton.	4.5 / 60	Stable
1D.19	Fault at 80% of line from Pendleton 138 kV to Meadowbrook – Madison circuit. Delayed clearing at Pendleton.	4.5 / 60	Stable

Table 7: Single-phase Faults With Loss of Multiple-Circuit Tower Line

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AA2-148 No Mitigation
1T.01	Fault at Tanners Creek 345 kV on V4-033 (Desoto) circuit 2 resulting in tower failure. Fault cleared with loss of U2-090 (Desoto) circuit 2. CONTINGENCY 6873'	4.5	Stable
1T.02	Fault at V4-033 345 kV on U2-090 (Desoto) circuit 2 resulting in tower failure. Fault cleared with loss of Tanners Creek circuit 2 (Trips V4-033). CONTINGENCY '8713'	4.5	Stable
1T.03	Fault at Tanners Creek 138 kV on W4-004/008/AA2-148 circuit 1 resulting in tower failure. Fault cleared with loss of W4-004/AA2-148 circuit 2.	4.5	Stable
1T.04	Fault at Madison 138 kV on W4-004/AA2-148 circuit 1 resulting in tower failure. Fault cleared with loss of Falls creek circuit.	4.5	Stable
1T.05	Fault at W4-004/AA2-148 138 kV on Madison circuit 1 resulting in tower failure. Fault cleared with loss of Pendleton circuit.	4.5	Stable
1T.06	Fault at Pendleton 138 kV on Fall Creek circuit 1 resulting in tower failure. Fault cleared with loss of W4-004/AA2-148 circuit.	4.5	Stable

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Additional Interconnection Customer Responsibilities:

1. An Interconnection Customer entering the New Services Queue on or after October 1, 2012 with a proposed new Customer Facility that has a Maximum Facility Output equal to or greater than 100 MW shall install and maintain, at its expense, phasor measurement units (PMUs). See Section 8.5.3 of Appendix 2 to the Interconnection Service Agreement as well as section 4.3 of PJM Manual 14D for additional information.

2. The Interconnection Customer may be required to install and/or pay for metering as necessary to properly track real time output of the facility as well as installing metering which shall be used for billing purposes. See Section 8 of Appendix 2 to the Interconnection Service Agreement as well as Section 4 of PJM Manual 14D for additional information.

Appendices

The following appendices contain additional information about each flowgate presented in the body of the report. For each appendix, a description of the flowgate and its contingency was included for convenience. However, the intent of the appendix section is to provide more information on which projects/generators have contributions to the flowgate in question. Although this information is not used "as is" for cost allocation purposes, it can be used to gage other generators impact.

It should be noted the generator contributions presented in the appendices sections are full contributions, whereas in the body of the report, those contributions take into consideration the commercial probability of each project.

Appendix 1

(AEP - AEP) The 05HOGAN-05DELAWR 138 kV line (from bus 243311 to bus 243275 ckt 1) loads from 114.7% to 121.58% (AC power flow) of its emergency rating (179 MVA) for the line fault with failed breaker contingency outage of '2965_C2_05DESOTO 345-A2'. This project contributes approximately 14.51 MW to the thermal violation.

CONTINGENCY '2965_C2_05DESOTO 345-A2'
OPEN BRANCH FROM BUS 243218 TO BUS 243222 CKT 1 / 243218 05DESOTO 345 243222 05FALL C 345 1
OPEN BRANCH FROM BUS 243218 TO BUS 243278 CKT 1 / 243218 05DESOTO 345 243278 05DESOTO 138 1
END

Bus Number	*Bus Name*	*Full Contribution*
246991	*05WLD G1 C*	*0.29*
247914	*05WLD G1 E*	*16.74*
247255	*05WLD G2 C*	*0.3*
247958	*05WLD G2 E*	*17.56*
247946	*W4-004 E*	*6.49*
247953	*W4-008 E*	*6.49*
920102	*AA2-106 E*	*2.21*
920501	*AA2-148 C OP*	*1.89*
920502	*AA2-148 E OP*	*12.62*