Queue Project AE1-104

Revised System Impact Study Report

Revised June 2021

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Preface

The intent of the System Impact Study is to determine a plan, with approximate cost and construction time estimates, to connect the subject generation interconnection project to the PJM network at a location specified by the Interconnection Customer. As a requirement for interconnection, the Interconnection Customer may be responsible for the cost of constructing: Network Upgrades, which are facility additions, or upgrades to existing facilities, that are needed to maintain the reliability of the PJM system. All facilities required for interconnection of a generation interconnection project must be designed to meet the technical specifications (on PJM web site) for the appropriate transmission owner.

In some instances an Interconnection Customer may not be responsible for 100% of the identified network upgrade cost because other transmission network uses, e.g. another generation interconnection or merchant transmission upgrade, may also contribute to the need for the same network reinforcement. The possibility of sharing the reinforcement costs with other projects may be identified in the Feasibility Study, but the actual allocation will be deferred until the System Impact Study is performed.

The System Impact Study estimates do not include the feasibility, cost, or time required to obtain property rights and permits for construction of the required facilities. The Interconnection Customer is responsible for the right of way, real estate, and construction permit issues. For properties currently owned by Transmission Owners, the costs may be included in the study.

General

Ocean Wind LLC, the Interconnection Customer (IC), has proposed a 432.0 MW (121.4 MW Capacity) offshore wind generating facility to be located in the Atlantic Ocean east of Ocean City, New Jersey at coordinates 39.2314082, -74.2913980. PJM studied the AE1-104 project as an injection into the Atlantic City Electric Company (ACE) transmission system at the BL England 138 kV Substation (PSSE bus #228110) and evaluated it for compliance with reliability criteria for summer peak conditions in 2022. The project was studied at a commercial probability of 100%. The current planned in-service date, as requested by the IC, is June 1, 2023. This date may not be attainable due to required PJM studies (Facilities) and the Transmission Owner’s construction schedule for network upgrades.

Revision History

This System Impact Study report was revised in December 2019 to include the results of a Stability Analysis. The Stability Analysis Report can be found in Attachment 2.

The report was revised in April 2021 to reflect the results of a load flow retool study. It was further revised in June 2021 to make adjustments to report formatting and the diagram in the Stability Analysis section.

Point of Interconnection

The Interconnection Customer requested a transmission level Point of Interconnection (POI). Therefore, the POI will be located at an Interconnection Customer owned circuit breaker located within 500 ft. of ACE's 138 kV BL England Substation where it will connection to a new 138 kV bus position (see Attachment 1).

Transmission Owner Scope of Attachment Facilities Work

Substation Interconnection Estimate

Scope: Build a new position onto the 138 kV bus at BL England Substation. The new position will be connected to the AE1-104 generator. The project will require the addition of one (2) 138 kV breaker, three (3) 138 kV disconnect switches, three (3) CT/VT combination units, and substation bus.

Estimate: $6,500,000

Construction Time: 36-48 months

Major Equipment Included in Estimate:

Power Circuit Breaker, 138 kV, 3 cycle	Qty. 2
Breaker Disconnect, 138 kV	Qty. 4
Line Disconnect, 138 kV	Qty. 1
Double 1590 ACSR (325')	Qty. 3
Insulators, 138 kV	Qty. 21
Disconnect Switch Stand, Low, 138 kV, Steel	Qty. 1
Relay Panel, Transmission Line, FL/BU (20")	Qty. 1
Control Panel, 138 kV Circuit Breaker (10")	Qty. 1
Take-off structure, 138 kV	Qty. 2
138 kV Lightning Arresters	Qty. 3
138 kV Lightning Arresters Stands	Qty. 3

Estimate Assumptions:

- Upgrade of existing circuit breaker A & B to 3000A rating (see "Attachment 1").
- Current bus work is adequate to support AE1-104 new generation input.

- At proposed IC, Generator 1 has been completely disengaged/disassembled.
- Previous operator does not maintain rights or legal interests.
- Room in Control Enclosure for New Relay Panel.
- Fiber optic cable necessary is 1,000 linear feet.
- Developer to purchase additional land for substation expansion.
- Existing AC & DC systems are adequate
- Existing ground grid and storm water management requires southward expansion.

Required Relaying and Communications

New protection relays are required for the new terminals.

Front line and back-up line protection will be required. A relay panel for the generator bus will be required with front line and back-up protection.

A breaker control relay on a breaker control panel will be required for the control and operation of each new 138 kV circuit breaker (2 total).

The project will require re-wiring and adjustment of existing relay schemes to accommodate the new 138 kV position at the substation.

Metering

A three phase 138 kV revenue metering point will need to be established within the IC facility at the POI.

The IC will purchase and install all metering instrument transformers, as well as construct a metering structure per ACE's specifications. The secondary wiring connections at the instrument transformers will be completed by the IC's contractors and inspected by ACE, while the secondary wiring work at the metering enclosure will be completed by ACE's meter technicians. The metering control cable and meter cabinets will be supplied by ACE and installed by the IC's contractors. ACE's meter technicians will program and install two solid state multi-function meters (Primary & Backup) for each new metering position. Each meter will be equipped with load profile, telemetry, and DNP outputs. The IC will be provided with one (1) meter DNP output.

The IC will be required to make provisions for a POTS (plain old telephone service) line within approximately three (3) feet of each ACE metering position to facilitate remote interrogation and data collection.

Interconnection Customer Scope of Direct Connection Work

The IC is responsible for all design and construction related to activities on their side of the Point of Interconnection. Site preparation, including grading and an access road, as necessary, is assumed to be by the IC. Route selection, line design, and right-of-way acquisition of the direct connect facilities is not included in this report, and is the responsibility of the IC. Protective relaying and metering design and installation must comply with ACE's applicable standards. The IC is also required to provide revenue metering and real-time telemetering data to PJM in conformance with the requirements contained in PJM Manuals M-01 and M-14 and the PJM Tariff.

ACE requires that an IC circuit breaker is located within 500 feet of the ACE substation to facilitate the relay protection scheme between ACE and the IC at the Point of Interconnection (POI).

Inverter Requirements

- The Interconnection Customer shall design is non-synchronous generation facility with the ability to maintain a power factor of at least 0.95 leading to 0.95 lagging measured at the Point of Interconnection.

Special Operating Requirements

1. ACE will require the capability to remotely disconnect the generator from the grid by communication from its System Operations facility. Such disconnection may be facilitated by a generator breaker, or other method depending upon the specific circumstances and the evaluation by ACE.
2. ACE reserves the right to charge the Interconnection Customer operation and maintenance expenses to maintain the Interconnection Customer attachment facilities, including metering and telecommunications facilities, owned by ACE.

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 seeking to interconnect a wind generation facility shall maintain meteorological data facilities as well as provide that meteorological data which is required per item 5.IV of Schedule H to the Interconnection Service Agreement.

Network Impacts

The Queue Project AE1-104 was evaluated as a 432.0 MW (Capacity 121.4 MW) injection BLE 138 kV substation in the AE area. Project AE1-104 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AE1-104 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Summer Peak Analysis - 2022

Generator Deliverability

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

None

Multiple Facility Contingency

(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)

None

Short Circuit

None

Affected System Analysis & Mitigation

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.

None

System Reinforcements – Summer Peak

Short Circuit

None

Stability and Reactive Power Requirement

None

Summer Peak Load Flow Analysis Reinforcements

New System Reinforcements

(Upgrades required to mitigate reliability criteria violations, i.e. Network Impacts, initially caused by the addition of this project generation)

None

Contribution to Previously Identified System Reinforcements

(Overloads initially caused by prior Queue positions with additional contribution to overloading by this project. This project may have a % allocation cost responsibility which will be calculated and reported for the Impact Study)

(Summary form of Cost allocation for transmission lines and transformers will be inserted here if any)

None

System Reinforcements - Light Load

New System Reinforcements

(Upgrades required to mitigate reliability criteria violations, i.e. Network Impacts, initially caused by the addition of this project generation)

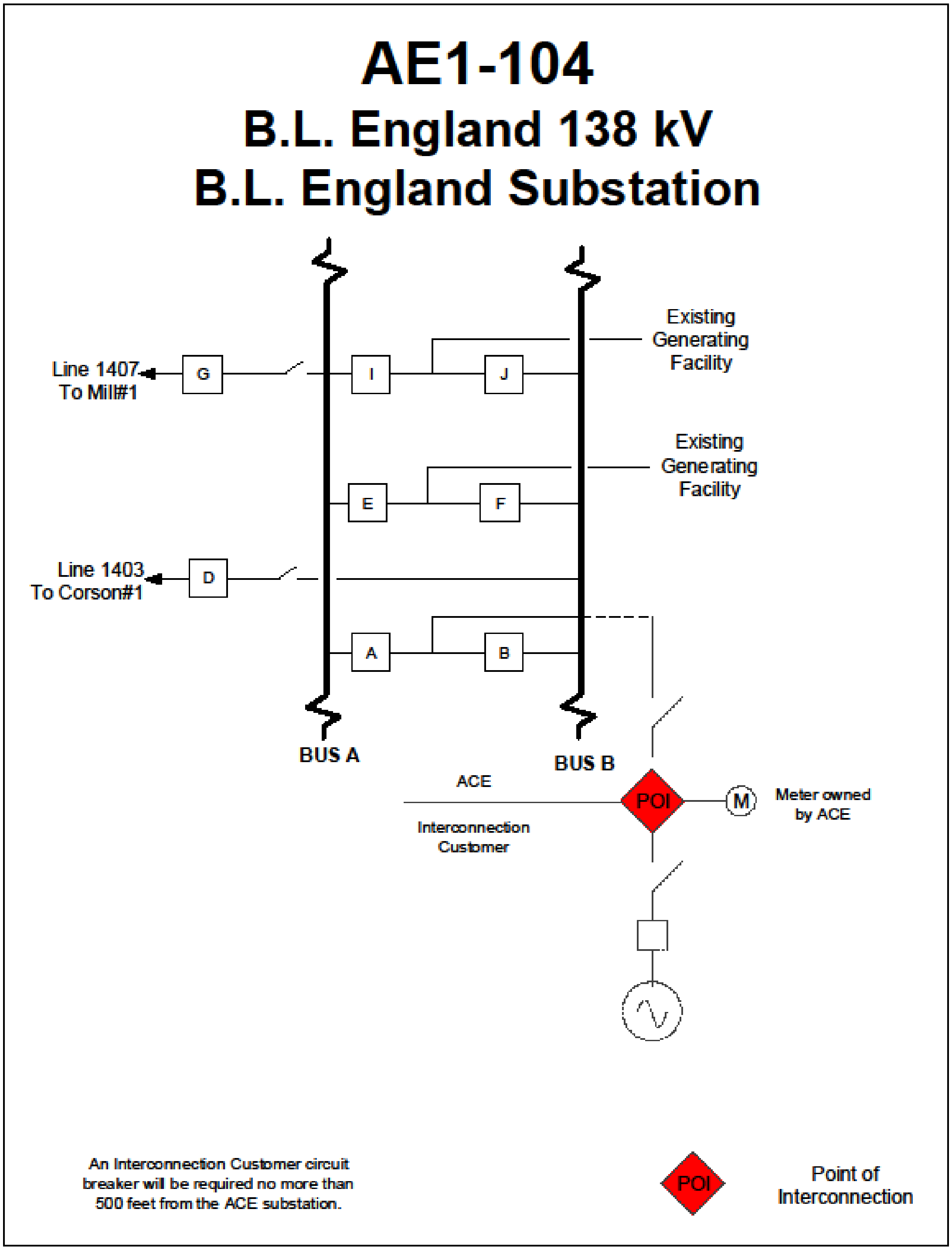
None

Contribution to Previously Identified System Reinforcements

(Overloads initially caused by prior Queue positions with additional contribution to overloading by this project. This project may have a % allocation cost responsibility which will be calculated and reported for the Impact Study)
(Summary form of Cost allocation for transmission lines and transformers will be inserted here if any)

None

Appendix A: One Line Diagram



Appendix B: Stability Study Results

AE1-104

System Impact Study

Dynamic Simulation Analysis

Prepared by	**CF Power Ltd**
For	**PJM Interconnection, LLC**
Reference	**AE1-104-3-4**
Date	**June 09, 2021**

Revision Table

Revision	Issue Date	Description
0	October 12, 2019	Initial Issue
1	October 28, 2019	Update the fault event definitions
2	April 28, 2020	Update the study by removing BLE#4 and W4-063
3	February 24, 2021	Re-study based on the updated data
4	June 09, 2021	Updated the SLD and model based on latest drawing. (re-run is not required)

Executive Summary

Generator Interconnection Request AE1-104 is for a 432 MW Maximum Facility Output (MFO) offshore wind generating facility, which consists of 38 GE HAL-X 12 MW wind turbines. The AE1-104 offshore wind generating facility will be located in the Atlantic Ocean east of Ocean City, New Jersey.

The AE1-104 offshore wind generating facility will connect to the BL England 138 kV substation in the Atlantic City Electric Company (ACE) transmission system. Project AE1-104 will connect to the substation via approximately 0.12 miles 138 kV transmission line. The Point of Interconnection (POI) will be where the Interconnection Customer generator lead line terminates at the BL England substation.

This report describes a dynamic simulation analysis of AE1-104 as part of the overall system impact study. The load flow scenario for the analysis was based on the RTEP 2022 peak load case, modified to include applicable queue projects. AE1-104 has been dispatched online at maximum power output, with approximately unity power factor and 1.0 pu voltage at the generator terminals.

AE1-104 was tested for compliance with NERC, PJM, Transmission Owner, and other applicable criteria. 88 contingencies were studied, each with a 20 second simulation time period (with 1.0 second initial run prior to any events). Studied faults included:

a) Steady state operation (Category P0);

b) Three phase faults with normal clearing time on the intact network (Category P1);

c) Single phase to ground faults with delayed clearing due to a stuck breaker (Category P4);

d) Single phase faults placed at 80% of the line with delayed (Zone 2) clearing at line end remote from the fault due to primary communications/relay failure (Category P5);

e) Single phase to ground faults with normal clearing for common structure (Category P7).

For all 88 fault contingencies tested on the 2022 peak load case:

a) AE1-104 was able to ride through the faults.

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

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 other transmission element trips, other than those either directly connected or designed to trip as a consequence of that fault.

Please also note that the project AE1-104 meets the 0.95 leading and lagging reactive power requirement at the high side of the facility main transformer.

1. Introduction

Generator Interconnection Request AE1-104 is for a 432 MW Maximum Facility Output (MFO) offshore wind generating facility, which consists of 38 GE HAL-X 12 MW wind turbines. The AE1-104 offshore wind generating facility will be located in the Atlantic Ocean east of Ocean City, New Jersey.

The AE1-104 offshore wind generating facility will connect to the BL England 138 kV substation in the Atlantic City Electric Company (ACE) transmission system. Project AE1-104 will connect to the substation via approximately 0.12 miles 138 kV transmission line. The Point of Interconnection (POI) will be where the Interconnection Customer generator lead line terminates at the BL England substation.

This analysis is effectively a screening study to determine whether the addition of AE1-104 will meet the dynamic requirements of the NERC, PJM, and Transmission Owner reliability standards.

In this report the AE1-104 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

Generator Interconnection Request AE1-104 is for a 432 MW Maximum Facility Output (MFO) offshore wind generating facility, which consists of 38 GE HAL-X 12 MW wind turbines. The AE1-104 offshore wind generating facility will be located in the Atlantic Ocean east of Ocean City, New Jersey.

The AE1-104 offshore wind generating facility will connect to the BL England 138 kV substation in the Atlantic City Electric Company (ACE) transmission system. Project AE1-104 will connect to the substation via approximately 0.12 miles 138 kV transmission line. The Point of Interconnection (POI) will be where the Interconnection Customer generator lead line terminates at the BL England substation.

The connection diagram of the AE1-104 offshore wind generating facility is shown in Figure 1. Table 1 lists the parameters given in the impact study data and the corresponding parameters of the AE1-104 loadflow model.

Additional project details are provided in Attachments 1 through 4:

- Attachment 1 contains the Impact Study Data which details the proposed AE1-104 project.
- Attachment 2 shows the one line diagram of the ACE network in the vicinity of AE1-104.
- Attachment 3 provides a diagram of the PSS/E model in the vicinity of AE1-104.
- Attachment 4 gives the PSS/E power flow and dynamic models of the AE1-104.

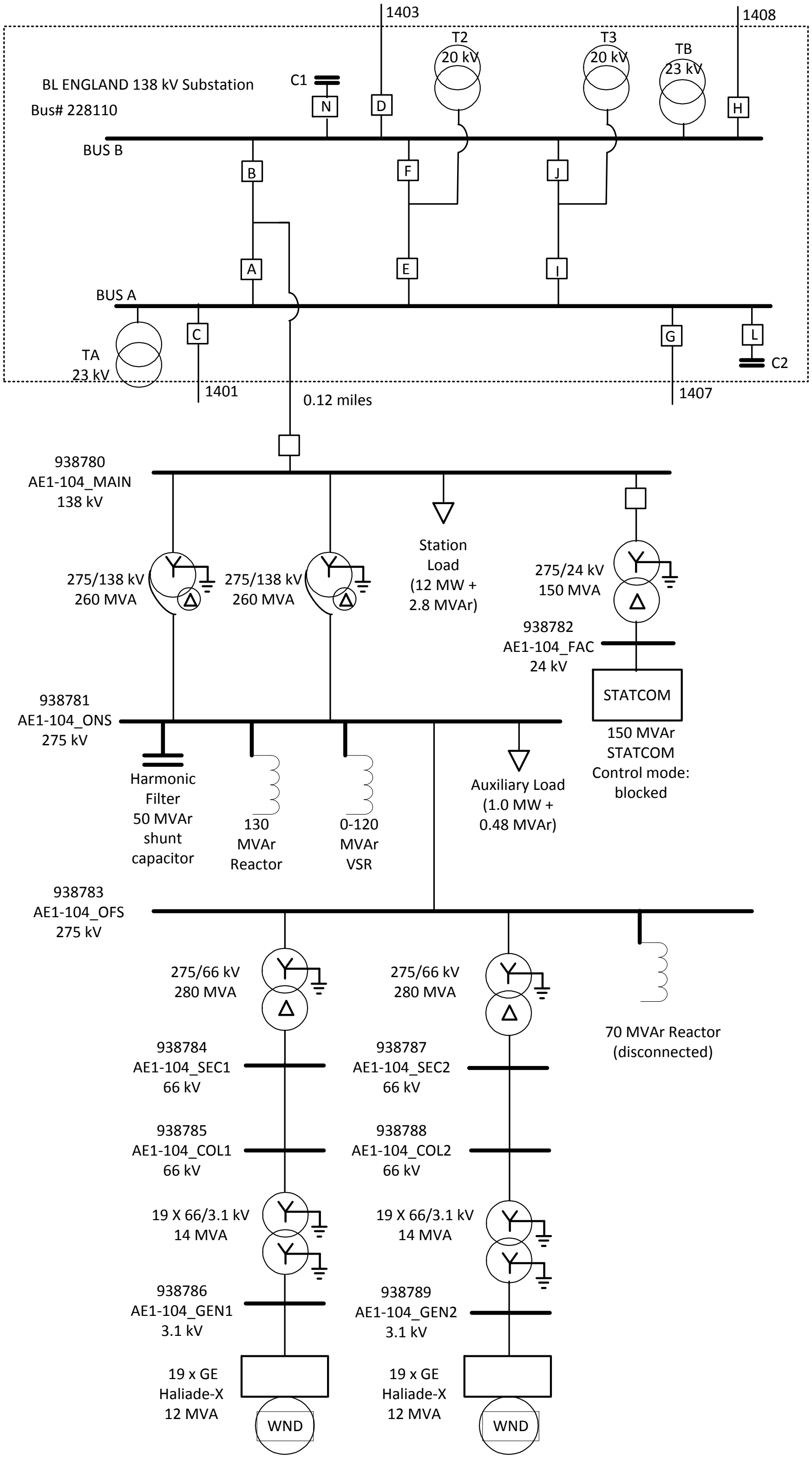


Figure 1: AE1-104 Plant Model

Table 1: AE1-104 Plant Model

	Impact Study Data	Model
Wind Turbines	38X12 MW GE HAL-X wind turbines MVA base = 12 MVA Vt = 3.1 kV Zsource = N/A Pgen[1] = 12.0 MW Qmax[2] = 8.28 MVAr Qmin = -5.4 MVAr	2 x 228 MW generator Pgen 228.0 MW Pmax 228.0 MW Pmin 0.0 MW Qgen 0.0 MVAr Qmax 157.32 MVAr Qmin -102.6 MVAr Mbase 228.0 MVA Zsorce j9999pu @ Mbase
Inverter Based Step-up Transformers	38X 66/3.1 kV two winding transformer Rating = 14 MVA Transformer base = 14 MVA Impedance = 0.012858 + j0.179993 pu @ MVA base Number of taps = 7 Tap step size = 2.5	2 x 66/3.1 kV two winding transformer (YNyn) Rating = 266 MVA Transformer base = 266 MVA Impedance = 0.012858 + j0.179993 pu @ MVA base Number of taps = 7 Tap step size = 2.5 %

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[1] This information is from the document "AE1-104Package_PJM_Feb4_2021.zip" and its attachments.

[2] The Leading and lagging values are obtained from "HAL-X 12MW 60Hz PQ curve.pdf".

	Impact Study Data	**Model**
Main Transformers	2 x 275/66 kV two winding transformer Rating = 280 MVA Transformer base = 280 MVA Impedance = 0.002036 + j0.109980 pu @ MVA base Number of taps = 21 Tap step size = 1.5	2 x 275/66 kV two winding transformer (YNd) Rating = 280 MVA Transformer base = 280 MVA Impedance = 0.002036 + j0.109980 pu @ MVA base Number of taps = 21 Tap step size = 1.5 %
Interconnection Main Transformers	2 x 275/138 kV autotransformer Rating = 260 MVA Transformer base = 260 MVA Impedance = 0.001732 + j0.099986 pu @ MVA base Number of taps = 21 Tap step size = 1.5	2 x 275/138 kV autotransformer (YNa) Rating = 260 MVA Transformer base = 260 MVA Impedance = 0.001732 + j0.099986 pu @ MVA base Number of taps = 21 Tap step size = 1.5 %

	Impact Study Data	**Model**
Collector System Equivalent 1	66 kV transmission cable Rating = 240 MVA MVA base = 100 MVA Impedance = 0.001000 + j0.001300 pu @ MVA base Charging susceptance = 0.111400 pu @ MVA base	66 kV transmission cable Rating = 240 MVA MVA base = 100 MVA Impedance = 0.001000 + j0.001300 pu @ MVA base Charging susceptance = 0.111400 pu @ MVA base
Collector System Equivalent 2	66 kV transmission cable Rating = 240 MVA MVA base = 100 MVA Impedance = 0.001200 + j0.001500 pu @ MVA base Charging susceptance = 0.134200 pu @ MVA base	66 kV transmission cable Rating = 240 MVA MVA base = 100 MVA Impedance = 0.001200 + j0.001500 pu @ MVA base Charging susceptance = 0.134200 pu @ MVA base

	Impact Study Data	**Model**
Collector System Equivalent 3	275 kV transmission cable (Information from PSSE case)	275 kV transmission cable Rating = 480 MVA MVA base = 100 MVA Impedance = 0.001820 + j0.007870 pu @ MVA base Charging susceptance = 2.204200 pu @ MVA base
Transmission Line	0.12 miles 138 kV transmission line Rating = 480 MVA MVA base = 100 MVA Impedance = 0.000025 + j0.000232 pu @ MVA base Charging susceptance = 0.00542 pu @ MVA base	0.12 miles 138 kV transmission line Rating = 480 MVA MVA base = 100 MVA Impedance = 0.000025 + j0.000232 pu @ MVA base Charging susceptance = 0.00542 pu @ MVA base
Auxiliary load[3]	Active power = 1.0 MW Reactive power = 0.48MVAR	P = 1.0 MW Q = 0.48 MVAR Vt = 275 kV

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[3] According to the document “AE1-104Package_PJM_Feb4_2021.zip” and its attachments, the auxiliary load relates to the operations of the plant.

	Impact Study Data	**Model**
Station Load	Active power = 12.0 MW Reactive power = 2.48 MVAR	P = 12.0 MW Q = 2.48 MVAR Vt = 138 kV
Reactor R11[4]	70 MVar reactor at offshore 275 kV substation	70 MVar reactor at offshore 275 kV substation (Disconnected in model)
Reactor R12	130 MVar reactor at onshore 275 kV substation	130 MVar reactor at onshore 275 kV substation
Reactor R13	0-120 MVAr variable reactor at onshore 275 kV substation Vlo = 0.99 pu Vhi = 1.01 pu	0-120 MVAr variable reactor at onshore 275 kV substation Vlo = 0.99 pu Vhi = 1.01 pu
Harmonic Filter 11	Equivalent 50 MVar shunt capacitor at onshore 275 kV substation	Equivalent 50 MVar shunt capacitor at onshore 275 kV substation
STATCOM	150 MVAr STATCOM at onshore 275 kV substation Control mode: Normal	150 MVAr STATCOM at onshore 275 kV substation Control mode: Blocked

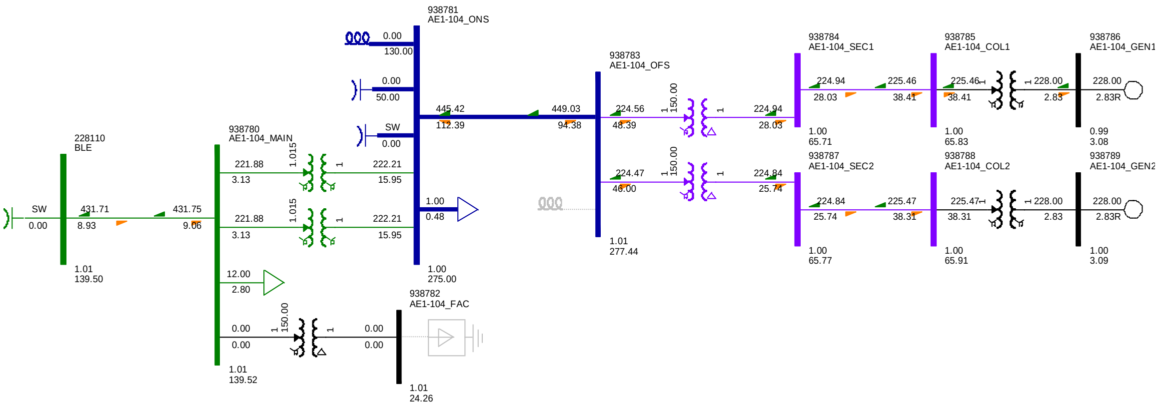

Figure 2: AE1-104 Single Line Diagram (PSS/E)

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[4] According to the document "AE1-104Package_PJM_Feb4_2021.zip"

3. Reactive Power Assessment

AE1-104 was assessed for compliance with reactive power capability requirements using the supplied capability curves. Please note this is a new facility.

- Generation shall have the ability to maintain a power factor of at least 0.95 leading to 0.95 lagging at the high side of facility transformer or the result of the System Impact Study indicated that, for the safety and reliably of the Transmission System, no power factor requirement is required[5].[6]

Generator	MFO	Required pF Range		Maximum (Lagging)	Minimum (Leading)
		Lagging	Leading		
AE1-104	432	0.95	0.95		
Total MVAR Required				141.99	-141.99
MVAR from Generators				Qmax	Qmin
				314.64	-205.20
Customer Planned Compensation[7]				50	-250
Qloss				126.66	-86.12
Total Available MVAR at High Side of Facility Transformer				491.30	-541.32
Deficiency in MVAR				**Meet**	**Meet**

The offshore wind generating facility AE1-104 **meets** the reactive power requirement at the high side of main facility transformer.

4. MFO Assessment

The MFO of AE1-104 was also assessed and found that the MFO at POI is **lower than or equal to** the requested MFO.

	Active Power (MW)
Requested Gross MW	456
Requested MFO	432

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[5] As specified in the document "Reactive Power Requirements.doc", Date: 6/15/2018.

[6] As specified in Attachment O of the document "PJM Open Access Transmission Tariff" Effective Date: 4/23/2018.

[7] Reactors, shunt capacitors, and STATCOM

Aux+SS	13.0
Losses and local load	11.25
MFO at the POI	431.75
MFO at the POI <= Requested MFO	**Yes**

5. Loadflow and Dynamics Case Setup

The dynamics simulation analysis was carried out using PSS/E Version 33.

The load flow scenario and fault cases for this study are based on ACE planning criteria[8], PJM's Regional Transmission Planning Process[9] and discussions with PJM.

The selected load flow scenario is the RTEP 2022 peak load case with the following modifications:

a) Addition of all applicable queue projects prior to AE1-104.

b) Addition of AE1-104 queue project.

c) Removal of withdrawn and subsequent queue projects in the vicinity of AE1-104.

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

In the load flow the AE1-104 generators were set to maximum power output, with approximately unity power factor and 1.0 pu voltage at the generator bus.

Table 2: AE1-104 machine initial conditions

Bus	Name	Unit	PGEN (MW)	QGEN (Mvar)	ETERM (pu)	POI Voltage (pu)
938786	AE1-104_GEN1	1	228	-2.83	1.00	1.01
938789	AE1-104_GEN2	1	228	-2.83	1.00	1.01

Generation within the vicinity (within five buses) of AE1-104 has been dispatched online at maximum output (PMAX). The dispatch within the ACE area is given in Attachment 5.

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[8] Atlantic City Electric – FERC Form 715 (Part 4) – Transmission Planning Study Guidelines, https://www.pjm.com/-/media/planning/planning-criteria/ exelon-planning-criteria.ashx?la=en.

[9] Manual 14B: PJM Region Transmission Planning Process, Rev 44, February 21, 2019, Attachment G: PJM Stability, Short Circuit, and Special RTEP Practices and Procedures.

6. Fault Cases

The project was tested for compliance with NERC, ACE, PJM, and other applicable criteria. 88 contingencies were studied, each with a 20 second simulation time period (with 1.0 second initial run prior to any events). Contingencies to be studied include:

a) Steady state operation (Category P0);

b) Three phase faults with normal clearing time on the intact network (Category P1);

c) Single phase to ground faults with delayed clearing due to a stuck breaker (Category P4);

d) Single phase faults placed at 80% of the line with delayed (Zone 2) clearing at line end remote from the fault due to primary communications/relay failure (Category P5);

e) Single phase to ground faults with normal clearing for common structure (Category P7).

No High Speed Reclosing (HSR) contingencies were found in the vicinity of AE1-104[10].

Buses at which the faults listed above were applied are:

- AE1-104 Main 138 kV
- BL England 138 kV
- Mill 138 kV
- Corson 138 kV
- Merion 138 kV
- Dennis 230/138 kV

Table 3 gives the details of typical fault clearing time[11] for 230kV and 138 kV breakers at ACE.

Table 3: AE1-104 breaker details

TO	Circuit Breaker	Three Phase Fault Normal Clearing Time (cycles)	SLG Delayed Clearing Time due to Stuck Breaker (cycles)	SLG Delayed Clearing Time due to Primary Relay Failure (cycles)
138 kV	All Breakers	9	23	41
230 kV	All Breakers	7	18.5	38

A complete list of the contingencies that were studied is given in Table 6 to Table 10.

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[10] PJM_HighSpeedReclosing_List.xlsx

[11] Rev. 20 of “2017 Revised Clearing time for each PJM company_Rev20.xls”

7. Evaluation Criteria

This study is focused on AE1-104, 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) AE1-104 is able to ride through the faults (except for faults where protective action trips the generator(s)).

b) The system with AE1-104 included is transiently stable and post-contingency oscillations should be positively damped with a damping margin of at least 3%.

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.

8. Summary of Results

Plots from the dynamic simulations are provided in Attachment 6, with results shown in Table 6 through Table 10.

For all 88 fault contingencies tested on the 2022 peak load case:

a) AE1-104 was able to ride through the faults.

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

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 other transmission element trips, other than those either directly connected or designed to trip as a consequence of that fault.

No mitigation measure is required from transient stability perspective.

Table 4: Summary of Machine Tripped by Protective Action

Contingency	Time [s]	Unit	Bus	Protective Action
None	-	-	-	-

Network non-convergence was also observed as summarized in Table 5.

Table 5: Summary of Network Non-Convergence

Contingency	Time [s]	Unit	Bus
P1.01*~P1.23*	1.0~1.1542	AE1-104 GEN1 AE1-104_GEN2	938786 938789
P1.24*~P1.27*	1.0, 1.0042	AE1-104 GEN1 AE1-104_GEN2	938786 938789
P4.1B1.01*	1.0~1.0083	AE1-104 GEN1 AE1-104_GEN2	938786 938789
P4.1B1.02~.07, .25~.28*	1.0, 1.0042	AE1-104 GEN1 AE1-104_GEN2	938786 938789
P5.01, .06, .17*	1.0, 1.0042	AE1-104 GEN1 AE1-104_GEN2	938786 938789
P5.02*	1.0~1.0083	AE1-104 GEN1 AE1-104_GEN2	938786 938789
P7.01, .03*	1.0, 1.0042	AE1-104 GEN1 AE1-104_GEN2	938786 938789

* Non-convergence during fault that should not be a problem if it recovers back after the fault is removed.

Table 6: Steady State Operation – Category P0

Fault ID	Duration	AE1-104 No Mitigation
P0_01	Steady state 20 sec	Stable

Table 7: Three-phase Faults with Normal Clearing – Category P1

Fault ID	Fault description	Clearing Time & Reclose (Cycles)	AE1-104 No Mitigation
P1.01	3ph fault @ AE1-104 138 kV Main on AE1-104 circuit. Trips AE1-104	9	Stable
P1.02	3ph fault @ BL England 138 kV on AE1-104 circuit. Trips AE1-104	9	Stable
P1.03	3ph fault @ BL England 138 kV on Scull - Mill circuit 1407, loss of Scull 138/12.9 kV TR#1	9	Stable
P1.04	3ph fault @ BL England 138 kV on Scull -Mill circuit 1408, loss of Scull 138/12.9 kV TR#2	9	Stable
P1.05	3ph fault @ BL England 138 kV on Corson circuit 1403, loss Middle circuit 1413 and circuit 1403	9	Stable
P1.06	3ph fault @ BL England 138 kV on Merion circuit 1401, loss of Merion 138/12.9 kV TR#2	9	Stable
P1.07	3ph fault @ Mill 138 kV on Scull - BL England circuit 1407, loss of Scull 138/12.9 kV TR#1	9	Stable
P1.08	3ph fault @ Mill 138 kV on Scull - BL England circuit 1408, loss of Scull 138/12.9 kV TR#2	9	Stable
P1.09	3ph fault @ Mill 138 kV on Lewis circuit 1423	9	Stable
P1.10	3ph fault @ Mill 138 kV on Lewis circuit 1424	9	Stable
P1.11	3ph fault @ Mill 138 kV on 138/69 kV T1	9	Stable
P1.12	3ph fault @ Corson 138 kV on BL England circuit 1403, loss Middle circuit 1413 and circuit 1403	9	Stable
P1.13	3ph fault @ Corson 138 kV on Merion circuit 1411, loss of Merion 138/12.9 kV TR#1	9	Stable
P1.14	3ph fault @ Corson 138 kV on Dennis circuit 1417	9	Stable
P1.15	3ph fault @ Corson 138 kV on Middle circuit 1413, loss of BL England Circuit	9	Stable
P1.16	3ph fault @ Corson 138 kV on Union circuit 1402	9	Stable
P1.17	3ph fault @ Corson 138 kV on Middle circuit 1412	9	Stable
P1.18	3ph fault @ Corson 138 kV on 138/69 kV T1, loss Merion circuit 1411 and T1	9	Stable
P1.19	3ph fault @ Corson 138 kV on 138/69 kV T2	9	Stable
P1.20	3ph fault @ Merion 138 kV on BL England circuit 1401, loss of Merion 138/12.9 kV TR#2	9	Stable
P1.21	3ph fault @ Merion 138 kV on Corson circuit 1411, loss of Merion 138/12.9 kV TR#1	9	Stable
P1.22	3ph fault @ Dennis 138 kV on Corson circuit 1417	9	Stable
P1.23	3ph fault @ Dennis 138 kV on 230/138 kV T2, loss Corson circuit 1417 and T2	9	Stable

Fault ID	Fault description	Clearing Time & Reclose (Cycles)	AE1-104 No Mitigation
P1.24	3ph fault @ Dennis 230 kV on 230/138 kV T2, loss Corson circuit 1417 and T2	7	Stable
P1.25	3ph fault @ Dennis 230 kV on Cumberland circuit 2307	7	Stable
P1.26	3ph fault @ Dennis 230 kV on 230/69 kV T3	7	Stable
P1.27	3ph fault @ Dennis 230 kV on SVC and capacitor bank	7	Stable

Table 8: Single-phase Faults with Stuck Breaker – Category P4

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	AE1-104 No Mitigation
P4_1B1.01	SLG @ AE1-104 138 kV on BL England circuit. Breaker stuck at AE1-104 POI. SLG @ AE1-104 138 kV due to breaker failure, fault cleared with loss of AE1-104	9/23	Stable
P4_1B1.02	SLG @ BL England 138 kV on AE1-104 circuit. Breaker B stuck at BL England. SLG @ BL England 138 kV due to breaker failure, fault cleared with loss of Corson circuit 1403, Scull-Mill circuit 1408, Bus B, and Cap 1.	9/23	Stable
P4_1B1.03	SLG @ BL England 138 kV on AE1-104 circuit. Breaker A stuck at BL England. SLG @ BL England 138 kV due to breaker failure, fault cleared with loss of Scull-Mill circuit 1407, Merion circuit 1401, Bus A, and Cap 2.	9/23	Stable
P4_1B1.04	SLG @ BL England 138 kV on Scull - Mill circuit 1408, Breaker H stuck at BL England. SLG @ BL England 138 kV due to breaker failure, fault cleared with loss Corson circuit 1403, Bus B, and Cap 1	9/23	Stable
P4_1B1.05	SLG @ BL England 138 kV on Scull - Mill circuit 1407, Breaker G stuck at BL England. SLG @ BL England 138 kV due to breaker failure, fault cleared with loss Merion circuit 1401, Bus A, and Cap 2	9/23	Stable
P4_1B1.06	SLG @ BL England 138 kV on Corson circuit 1403, Breaker D stuck at BL England. SLG @ BL England 138 kV due to breaker failure, fault cleared with loss Scull-Mill circuit 1408, Bus B, and Cap 1	9/23	Stable
P4_1B1.07	SLG @ BL England 138 kV on Merion circuit 1401, loss of Merion 138/12.9 kV TR#2, Breaker C stuck at BL England. SLG @ BL England 138 kV due to breaker failure, fault cleared with loss Scull-Mill circuit 1407, Bus A, and Cap 2	9/23	Stable
P4_1B1.08	SLG @ Mill 138 kV on Lewis circuit 1423, Breaker D stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with loss Mill 138/69 kV T1	9/23	Stable
P4_1B1.09	SLG @ Mill 138 kV on Lewis circuit 1423, Breaker Q stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable
P4_1B1.10	SLG @ Mill 138 kV on Scull-BL England circuit 1407, Breaker O stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable
P4_1B1.11	SLG @ Mill 138 kV on Scull-BL England circuit 1407, Breaker A stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable
P4_1B1.12	SLG @ Mill 138 kV on Scull-BL England circuit 1408, Breaker L stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	AE1-104 No Mitigation
P4_1B1.13	SLG @ Mill 138 kV on Scull-BL England circuit 1408, Breaker S stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable
P4_1B1.14	SLG @ Mill 138 kV on Lewis circuit 1424, Breaker G stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable
P4_1B1.15	SLG @ Mill 138 kV on Lewis circuit 1424, Breaker AW stuck at Mill. SLG @ Mill 138 kV due to breaker failure, fault cleared with loss Mill 138/69 kV T1	9/23	Stable
P4_1B1.16	SLG @ Corson 138 kV on Merion circuit 1411, loss of Merion 138/12.9 kV TR#1, Breaker E stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with loss Corson 138/69 kV T1	9/23	Stable
P4_1B1.17	SLG @ Corson 138 kV on Dennis circuit 1417, Breaker D stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with open breakers T, F, R, V	9/23	Stable
P4_1B1.18	SLG @ Corson 138 kV on BL England circuit 1403, Breaker R stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with open breakers T, D, F, V, G	9/23	Stable
P4_1B1.19	SLG @ Corson 138 kV on Union circuit 1402, Breaker S stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with loss Middle circuit 1412	9/23	Stable
P4_1B1.20	SLG @ Corson 138 kV on Middle circuit 1412, Breaker Q stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with loss Union circuit 1402	9/23	Stable
P4_1B1.21	SLG @ Corson 138 kV on Middle circuit 1413, Breaker G stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with loss BL England circuit 1403	9/23	Stable
P4_1B1.22	SLG @ Corson 138 kV on 138/69 kV T1, Breaker E stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with loss Merion circuit 1411	9/23	Stable
P4_1B1.23	SLG @ Corson 138 kV on 138/69 kV T1, Breaker T stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with open breakers D, F, R, V	9/23	Stable
P4_1B1.24	SLG @ Corson 138 kV on 138/69 kV T2, Breaker F stuck at Corson. SLG @ Corson 138 kV due to breaker failure, fault cleared with open breakers T, D, R, V	9/23	Stable
P4_1B1.25	SLG @ Merion 138 kV on BL England circuit 1401, Breaker C stuck at Merion. SLG @ Merion 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	AE1-104 No Mitigation
P4_1B1.26	SLG @ Merion 138 kV on BL England circuit 1401, Breaker B stuck at Merion. SLG @ Merion 138 kV due to breaker failure, fault cleared with loss Merion substation	9/23	Stable
P4_1B1.27	SLG @ Merion 138 kV on Corson circuit 1411, Breaker A stuck at Merion. SLG @ Merion 138 kV due to breaker failure, fault cleared with no additional element loss	9/23	Stable
P4_1B1.28	SLG @ Merion 138 kV on Corson circuit 1411, Breaker B stuck at Merion. SLG @ Merion 138 kV due to breaker failure, fault cleared with loss Merion substation	9/23	Stable
P4_1B1.29	SLG @ Dennis 138 kV on Corson circuit 1417, Breaker A stuck at Dennis. SLG @ Dennis 138 kV due to breaker failure, fault cleared with loss 230/138 kV T2.	9/23	Stable
P4_1B1.30	SLG @ Dennis 230 kV on 230/138 kV T2, Breaker F stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss Cumerland circuit 2307.	7/18.5	Stable
P4_1B1.31	SLG @ Dennis 230 kV on 230/138 kV T2, Breaker D stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss SVC and capacitors	7/18.5	Stable
P4_1B1.32	SLG @ Dennis 230 kV on Cumerland circuit 2307, Breaker F stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss 230/138 kV T2.	7/18.5	Stable
P4_1B1.33	SLG @ Dennis 230 kV on Cumerland circuit 2307, Breaker G stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss 230/69 kV T3.	7/18.5	Stable
P4_1B1.34	SLG @ Dennis 230 kV on 230/69 kV T3, Breaker G stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss Cumberland circuit 2307.	7/18.5	Stable
P4_1B1.35	SLG @ Dennis 230 kV on 230/69 kV T3, Breaker E stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss SVC and capacitors.	7/18.5	Stable
P4_1B1.36	SLG @ Dennis 230 kV on SVC and capacitors, Breaker E stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss 230/69 kV T3.	7/18.5	Stable
P4_1B1.37	SLG @ Dennis 230 kV on SVC and capacitors, Breaker D stuck at Dennis. SLG @ Dennis 230 kV due to breaker failure, fault cleared with loss 230/138 kV T2.	7/18.5	Stable

Table 9: Single-phase Faults with Delayed (Zone 2) Clearing due to Primary Communication/Relay Failure – Category P5

Fault ID	Fault description	Clearing Time (Cycles)	AE1-104 No Mitigation
P5.01	SLG @ 80% of 138 kV circuit from AE1-104 POI to BL England.	9/41	Stable
P5.02	SLG @ 80% of 138 kV circuit from BL England to AE1-104 POI	9/41	Stable
P5.03	SLG @ 80% of 138 kV circuit 1408 from BL England to Scull – Mill, loss of Scull 138/12.9 kV TR#2	9/41	Stable
P5.04	SLG @ 80% of 138 kV circuit 1407 from BL England to Scull – Mill, loss of Scull 138/12.9 kV TR#1	9/41	Stable
P5.05	SLG @ 80% of 138 kV circuit 1403 from BL England to Corson, loss of Corson – Middle circuit 1413	9/41	Stable
P5.06	SLG @ 80% of 138 kV circuit 1401 from BL England to Merion, loss of Merion 138/12.9 kV TR# 2	9/41	Stable
P5.07	SLG @ 80% of 138 kV circuit 1423 from Mill to Lewis	9/41	Stable
P5.08	SLG @ 80% of 138 kV circuit 1424 from Mill to Lewis	9/41	Stable
P5.09	SLG @ 80% of 138 kV circuit 1408 from Mill to Scull - BL England, loss of Scull 138/12.9 kV TR#2	9/41	Stable
P5.10	SLG @ 80% of 138 kV circuit 1407 from Mill to Scull - BL England, loss of Scull 138/12.9 kV TR#1	9/41	Stable
P5.11	SLG @ 80% of 138 kV circuit 1411 from Corson to Merion, loss of Merion 138/12.9 kV TR#1	9/41	Stable
P5.12	SLG @ 80% of 138 kV circuit 1417 from Corson to Dennis	9/41	Stable
P5.13	SLG @ 80% of 138 kV circuit 1403 from Corson to BL England, loss of Corson – Middle circuit 1413	9/41	Stable
P5.14	SLG @ 80% of 138 kV circuit 1402 from Corson to Union	9/41	Stable
P5.15	SLG @ 80% of 138 kV circuit 1412 from Corson to Middle	9/41	Stable
P5.16	SLG @ 80% of 138 kV circuit 1413 from Corson to Middle	9/41	Stable
P5.17	SLG @ 80% of 138 kV circuit 1401 from Merion to BL England, loss of Merion 138/12.9 kV TR#2	9/41	Stable
P5.18	SLG @ 80% of 138 kV circuit 1411 from Merion to Corson, loss of Merion 138/12.9 kV TR#1	9/41	Stable
P5.19	SLG @ 80% of 138 kV circuit 1417 from Denis to Corson	9/41	Stable
P5.20	SLG @ 80% of 230 kV circuit 2307 from Denis to Cumberland	7/38	Stable

Table 10: Single-phase Faults with Normal Clearing on Common Structure – Category P7

Fault ID	Fault description	Clearing Time (Cycles)	AE1-104 No Mitigation
P7.01	CONTINGENCY 'AE_P7-1 AE5TOWER' BLE TO OCITY 138 KV and BLE TO CORSON 138 KV	9.0	Stable
P7.02	CONTINGENCY 'AE_P7-1 AE6TOWER' MERION TO CORSON 138 KV and BLE TO CORSON 138 KV	9.0	Stable
P7.03	CONTINGENCY 'AE_P7-1 AE7TOWER' BLE TO SCULL TO MILL 138 KV and MILL TO LEWIS 138 KV	9.0	Stable