Generation Interconnection System Impact Study Report

For

PJM Generation Interconnection Request Queue Position AE1-115

"Churchtown 69 kV"

(Rev 1)

September 2019

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

Churchtown Battery Storage LLC, the Interconnection Customer (IC), has proposed a 20 MW Energy (10 MW Capacity) battery storage facility to be located at Latitude: 39.6736010 Longitude: -75.5034740 in Salem County, New Jersey. PJM studied the AE1-115 project as an injection into the Atlantic City Electric Company (ACE) transmission system at the Churchtown 69 kV Substation (PSSE bus #228319) 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 planned in-service date, as requested by the IC, is November 1, 2021. This date may not be attainable due to required PJM studies and the Transmission Owner's construction schedule.

Point of Interconnection

The Interconnection Customer requested a transmission level Point of Interconnection (POI) be evaluated for the AE1-115 project. As a result, the AE1-115 project will connect with the ACE transmission system at the Churchtown 69 kV Substation via a 69 kV line terminal (see Attachment 1).

The POI will be located at an IC owned breaker located within 500 ft. of ACE's 69 kV Churchtown substation where it will connection to a new 69 kV bus position.

Transmission Owner Scope of Attachment Facilities Work

Substation Interconnection Estimate
Scope: At Churchtown Substation, a 69kV SF6 gas circuit breaker with two (2) 69kV disconnect switches will be installed at 69kV ring bus to establish a new bus section for AE1-115. A set of 69kV CVTs will be installed at the new 69kv bus section for protective relays. A 69kV motor operated disconnect switch and lightning arresters will be installed at the 69kV terminal. A pre-fabricated relay panel with bus primary and backup protective relays and a 69kV breaker control relay will be installed in the existing 69kV control building. 600V control cable will be pulled from the location of 69kV circuit breaker, CVTs, and motor operated disconnect switch to the 69kV control building via the existing cable trench.

New foundation will be needed for 69kV SF6 gas circuit breaker and CVTs stand. A steel stand is needed for a set of 69kV CVTs.

Grounding to ground grid need to be installed for 69kV circuit breaker, CVTs and LAs.

Estimate: $2,300,000
Construction Time: 24-36 months

Major Equipment Included in Estimate:

- 69 kV SF6 Gas Circuit Breaker, 2000 A, 40 kA Interrupting Qty. 1
- 69 kV Disconnect Switch, 2000 A Qty. 2
- 69 kV Single Phase CVT Qty. 3
- 69 kV Motor Operated Disc. Switch, 2000A Qty. 1
- 48kV MCOV Station Class Lightning Arresters Qty. 3
- 69kV Bus Support Insulator Qty. 9
- Pre-fabricated Relay Panel (Bus FL/BU relays and CB Control Relay) Qty. 1
- 24"x20"x10" Control Cabinet for 69kV CVT Fuses Qty. 1

Grounding System:

- Two (2) grounding connection to ground grid for 69kV circuit breaker
- One (1) grounding connection to ground grid for 69kV CVTs
- Two (2) grounding connection to ground grid for LAs

Foundations:

- One (1) Foundation for 69kV SF6 gas circuit breaker
- One (1) Foundation for 69kV CVTs stand

Structures:

- One (1) Steel Stand for a set of 69kV CVTs

Bus:
- Approx. 300 ft 954 ACSR Wire
- Approx. 150 ft 477 MCM AL Wire

600V Control Cable:
- Approx. 6500 ft 4/C #10 AWG Cable
- Approx. 500 ft 7/C #10 AWG Cable
- Approx. 1500 ft 12/C #10 AWG Cable

Conduits / Trench:
- Two (2) 4" pvc conduits from 69kV breaker to Cable Trench (Approx. 40 ft)
- One (1) 4" pvc conduits from 69kV CVT stand to Cable Trench (Approx. 30 ft)
- One (1) 4" pvc conduit from 69kV MOD SW to Cable Trench (Approx. 30 ft)

Estimate Assumptions:
- Existing 69kV ring bus spare position will be used, no need to modify the existing bus configuration and 69kV box structure
- Interconnection line will be overhead line and terminate at the existing 69kv Box structure spare position. No need for new 69kV take-off structure or cable riser structure
- 69kV MOD switch will be mounted on the top of the existing 69kV Box structure. No need for new steel structure for 69kV MOD switch
- Fiber optic cable necessary is 1,000 linear feet.
- No new land will need to be purchased
- Existing AC&DC systems are adequate
- Existing communication system is adequate
- Existing Ground grid and storm water management are adequate

Required Relaying and Communications

New protection relays are required for the new terminal(s).

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 the 69 kV circuit breaker (1 total).

The project will require re-wiring and adjustment of existing relay schemes to accommodate the new 69 kV position at the substation.

Metering

A three phase 69 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.

Summer Peak Analysis - 2022

Transmission Network Impacts

Potential transmission network impacts are as follows:

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

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)

None

Short Circuit

No issues identified.

Stability Analysis

No issues identified. See Attachment 2 for full report.

Light Load Analysis - 2022

No issues identified.

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

Atlantic City Electric Costs

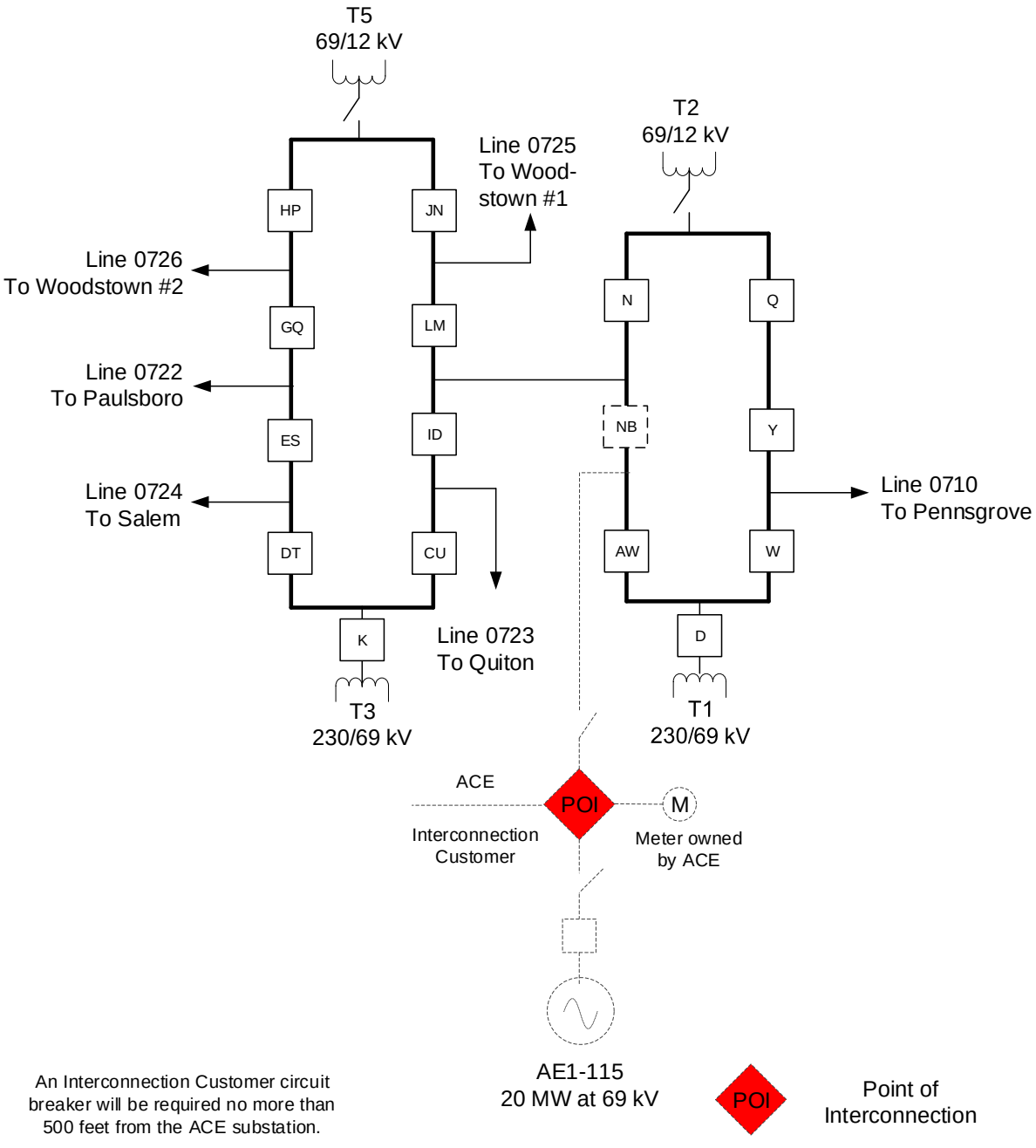
Cost estimates will further be refined as a part of the Impact Study and Facilities Study for this project. The Interconnection Customer will be responsible for all costs incurred by ACE in connection with the AE1-115 project.

Incremental Capacity Transfer Rights (ICTRs)

Will be determined at a later study phase.

Attachment 1

AE1-115
Churchtown 69 kV
Churchtown Substation



Attachment 2

AE1-115

System Impact Study

Dynamic Simulation Analysis

Executive Summary

Generator Interconnection Request AE1-115 is for a 20 MW Maximum Facility Output (MFO) inverter-connected battery energy storage facility, which consists of 9 SMA SCS 2750-EV-US inverters.

Project AE1-115 will directly connect into the Churchtown 69 kV substation via approximately 0.21 miles 69 kV transmission line. The Point of Interconnection (POI) will be where the Interconnection Customer generator lead line terminates at an open 69 kV line terminal at the Churchtown substation in the Atlantic City Electric Company (ACE) transmission system. The AE1-115 battery energy storage facility will be located in Salem County, New Jersey.

This report describes a dynamic simulation analysis of AE1-115 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. AE1-115 has been dispatched online at maximum power output, with unity power factor and approximately 1.0 pu voltage at the generator terminals.

AE1-115 was tested for compliance with NERC, PJM, Transmission Owner, and other applicable criteria. 78 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 78 fault contingencies tested on the 2022 peak load case:

a) AE1-115 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.

During initial simulations, it was found that the generator of AB1-169A lost its stability under an AE1-115 AP7.05 event which involved losing the 138 kV circuit between Landis and Minotola. The mitigation measure proposed by AB1-169A was then applied and all 78 fault contingencies were re-run. The results show that the system was transient stable with the application of AB1-169A mitigation measures.

Please note that the project AE1-115 meets the 0.95 leading and lagging reactive power requirement at the high side of facility main transformer.

1. Introduction

Generator Interconnection Request AE1-115 is for a 20 MW Maximum Facility Output (MFO) inverter-connected battery energy storage facility, which consists of 9 SMA SCS 2750-EV-US inverters.

Project AE1-115 will directly connect into the Churchtown 69 kV substation via approximately 0.21 miles 69 kV transmission line. The Point of Interconnection (POI) will be where the Interconnection Customer generator lead line terminates at an open 69 kV line terminal at the Churchtown substation in the Atlantic City Electric Company (ACE) transmission system. The AE1-115 battery energy storage facility will be located in Salem County, New Jersey.

This analysis is effectively a screening study to determine whether the addition of AE1-115 will meet the dynamic requirements of the NERC, PJM, and Transmission Owner reliability standards.

In this report the AE1-115 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 AE1-115 is for a 20 MW Maximum Facility Output (MFO) inverter-connected battery energy storage facility, which consists of 9 SMA SCS 2750-EV-US inverters.

Project AE1-115 will directly connect into the Churchtown 69 kV substation via approximately 0.21 miles 69 kV transmission line. The Point of Interconnection (POI) will be where the Interconnection Customer generator lead line terminates at an open 69 kV line terminal at the Churchtown substation in the Atlantic City Electric Company (ACE) transmission system. The AE1-115 battery energy storage facility will be located in Salem County, New Jersey.

The connection diagram of the AE1-115 generating facility is shown in Figure 1. Table 1 lists the parameters given in the impact study data and the corresponding parameters of the AE1-115 loadflow model.

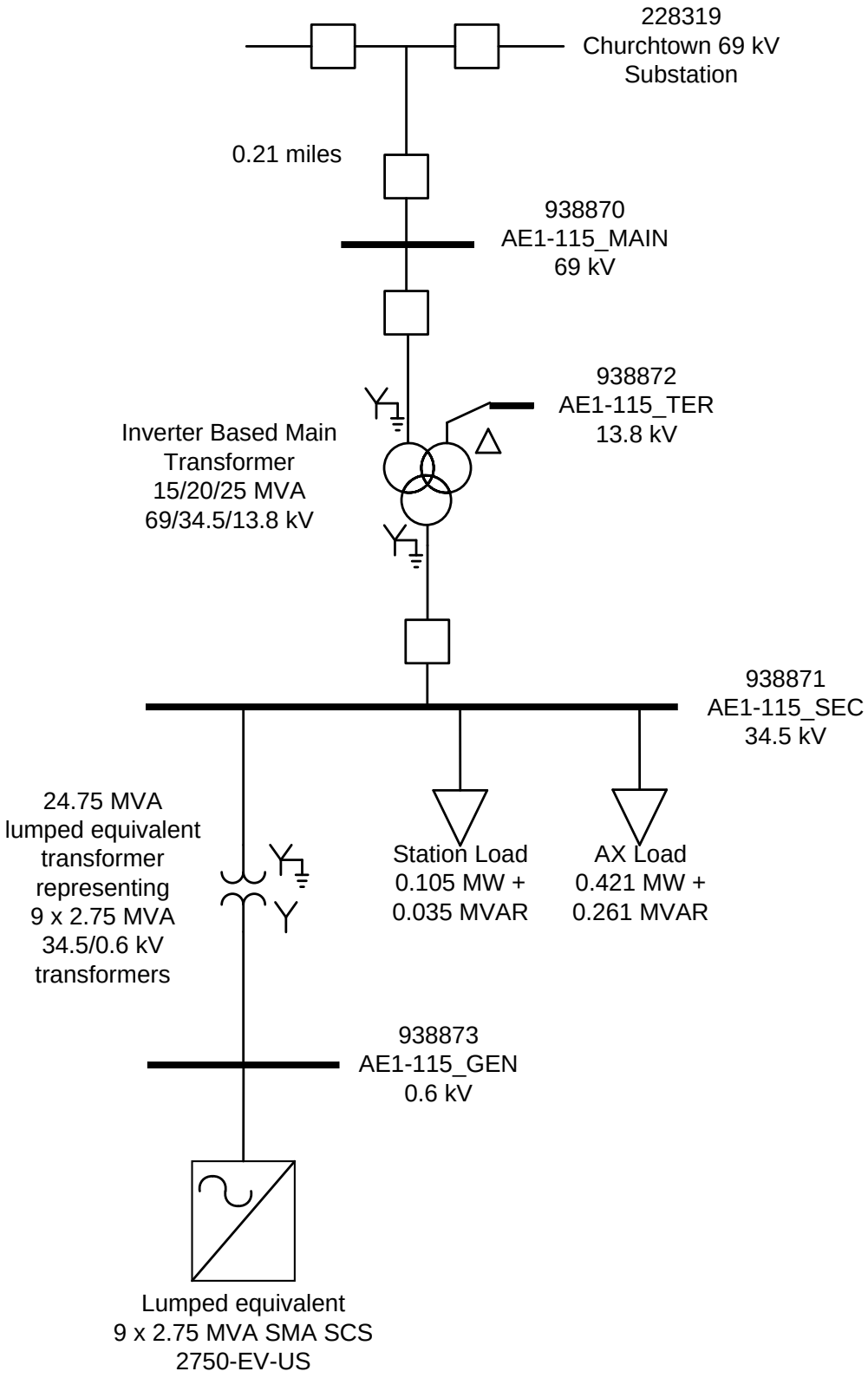


Figure 1: AE1-115 Plant Model

Table 1: AE1-115 Plant Model

	Impact Study Data	Model
Battery Energy Storage Inverters	9X2.75 MVA SMA SCS 2750-EV-US MVA base = 2.75 MVA Vt = 0.6 kV Zsource = N/A Pgen[1] = 2.222 MW Qmax[2] = 1.25 MVAr Qmin = -1.25 MVAr	1 x 24.75 MVA generator Pgen 20 MW Pmax 20 MW Pmin -20 MW Qgen 0.0 MVAr Qmax 11.25 MVAr Qmin -11.25 MVAr Mbase 24.75 MVA Zsorce j9999pu @ Mbase
Inverter Based Step-up Transformers	9X 34.5/0.6 kV transformer Rating = 2.75 MVA Transformer base = 2.75 MVA Impedance = 0.001437 + j0.057484 pu @ MVA base Number of taps = 5 Tap step size = 0.025 pu	1x 34.5/0.6 kV two winding transformer (YNy) Rating = 24.75 MVA Transformer base = 24.75 MVA Impedance = 0.001437 + j0.057484 pu @ MVA base Number of taps = 5 Tap step size = 2.5 %
Main Transformer	1x 69/34.5/13.8 kV transformer Rating = 15/20/25 MVA (ONAN/ONAF/OFAF) Transformer base = 20 MVA HL Impedance = 0.003745 + j0.074906 pu @ MVA base HT Impedance = 0.003226 + j0.077433 pu @ MVA base LT Impedance = 0.002082 + j0.049957 pu @ MVA base Number of taps = 33 Tap step size = 0.00625 pu	1x 69/34.5/13.8 kV transformer (YNYNd) Rating = 15/20/25 MVA Transformer base = 20 MVA HL Impedance = 0.003745 + j0.074906 pu @ MVA base HT Impedance = 0.003226 + j0.077433 pu @ MVA base LT Impedance = 0.002082 + j0.049957 pu @ MVA base Number of taps = 33 Tap step size = 0.625 %
Collector System Equivalent	None	None

[1] This information is from the document "Planning Center - Submission Admin - httpsqueuepoint-internalac2prodpjmcom.pdf" and its attachments.
[2] The Leading and lagging values are calculated based on "SCS2200-2750-EV-US-2900-DUS182626W.pdf" and "SMA SCS Generic Reactive Capability.pdf".

Transmission Line	0.21 miles 69 kV transmission line Rating = 0 MVA MVA base = 100 MVA Impedance = 0.004120 + j0.002376 pu @ MVA base Charging susceptance = 0.000828 pu @ MVA base	0.21 miles 69 kV transmission line Rating = 0 MVA MVA base = 100 MVA Impedance = 0.004120 + j0.002376 pu @ MVA base Charging susceptance = 0.000828 pu @ MVA base
Auxiliary load[3]	Active power = 0.421 MW Reactive power = 0.261 MVAR	P = 0.421 MW Q = 0.261 MVAR Vt = 34.5 kV
Station Load	Active power = 0.105 MW Reactive power = 0.035 MVAR	P = 0.105 MW Q = 0.035 MVAR Vt = 34.5 kV

[3] According to the document "Planning Center - Submission Admin - httpsqueuepoint-internalac2prodpjmcom.pdf" and its attachments", the auxiliary load and station load are connected at low voltage side of GSU.

3. Reactive Power Assessment

AE1-115 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[4].[5]

Generator	MFO	Required PF Range		Maximum (Lagging)	Minimum (Leading)
		Lagging	Leading		
AE1-115	20.0	0.95	0.95		
Total MVAR Required				6.57	-6.57
MVAR from Generators				Qmax	Qmin
				11.25	-11.25
Customer Planned Compensation				0	0
Qloss				-2.99	-3.64
Total Available MVAR at High Side of Main Transformer				8.26	-14.89
Deficiency in MVAR				**Meet**	**Meet**

The generating facility AE1-115 **meets** the reactive power requirement at the high side of facility main transformer.

4. MFO Assessment

The MFO of AE1-115 was also assessed and found that the MFO at POI is **lower** than the requested MFO.

	Active Power (MW)
Requested Gross MW	20
Requested MFO	20
Aux+SS	0.52
Losses	0.11
MFO at the POI	19.37
MFO at the POI <= Requested MFO	**Yes**

The auxiliary load and station service load were switched off when performing the dynamic analysis to ensure the MFO at the POI is close enough to the requested MFO. After the station service load and the auxiliary load were switched off, the MFO at the

[4] As specified in the document "Reactive Power Requirements.doc", Date: 6/15/2018.
[5] As specified in Attachment O of the document "PJM Open Access Transmission Tariff" Effective Date: 4/23/2018.

POI increased from 19.37 MW to 19.89 MW which is close enough to meet MFO requirement.

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[6], PJM's Regional Transmission Planning Process[7] 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 AE1-115.

b) Addition of AE1-115 queue project.

c) Removal of withdrawn and subsequent queue projects in the vicinity of AE1-115.

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

In the load flow the AE1-115 generators are set to maximum power output, with unity power factor and approximately 1.0 pu voltage at the generator bus.

Table 2: AE1-115 machine initial conditions

Bus	Name	Unit	PGEN (MW)	QGEN (MVar)	ETERM (pu)	POI Voltage (pu)
938873	AE1-115_GEN	1	20	-5.65	1.0000	1.0360

Generation within the vicinity (within five buses) of AE1-115 has been dispatched online at maximum output (PMAX).

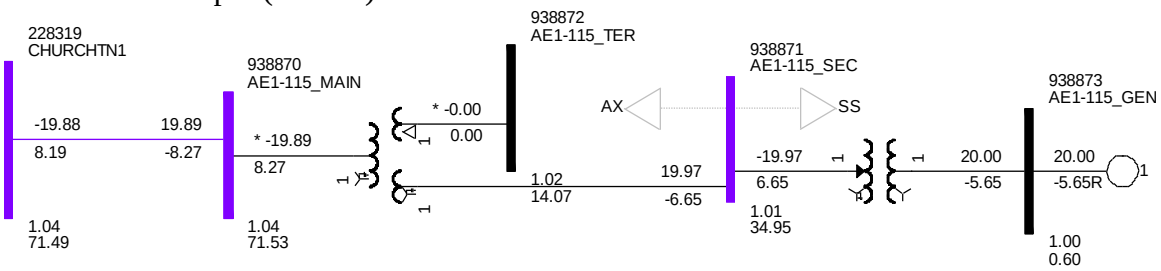


Figure 2: AE1-115 Single Line Diagram (PSS/E)

[6] 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.
[7] 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. 78 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 AE1-115[8]. Buses at which the faults listed above were applied are:

- Churchtown 240/138/69 kV
- Pennsgrove 69 kV
- Woodstown 69 kV
- Quinton 69 kV

Table 3 gives the details of typical fault clearing time[9] for 69 kV, 138 kV and 230 kV breakers at ACE.

Table 3: AE1-115 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)
ACE	69 kV	9	24	42
ACE	138 kV	9	23	41
ACE	230 kV	7	18.5	38

A complete list of the contingencies that were studied is given in Table 4 to Table 8.

[8] PJM_HighSpeedReclosing_List.xlsx
[9] Rev. 20 of "2017 Revised Clearing time for each PJM company_Rev20.xls"

7. Evaluation Criteria

This study is focused on AE1-115, 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) AE1-115 is able to ride through the faults (except for faults where protective action trips the generator(s)),

b) The system with AE1-115 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

Dynamic simulations are provided with results summarized in Table 4 through Table 8. During initial simulations, it was found that the generator of AB1-169A lost its stability under an AE1-115 P7.05 event which involved losing the 138 kV circuit between Landis and Minotola. The mitigation measure proposed by AB1-169A was then applied and all 78 fault contingencies were re-run. The results show that the system was transient stable with the application of AB1-169A mitigation measures.

For all 78 fault contingencies tested on the 2022 peak load case:

a) AE1-115 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.

Table 4: Steady State Operation – Category P0

Fault ID	Duration	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P0_01	Steady state 20 sec	Stable	Stable

Table 5: Three-phase Faults with Normal Clearing – Category P1

Fault ID	Fault description	Clearing Time & Reclose (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P1.01	3ph fault @ Churchtown 69 kV on AE1-115 circuit, normal cleared with loss of AE1-115 generation unit	9	Stable	Stable
P1.02	3ph fault @ Churchtown 69 kV on 230/69 kV TR#1, normal cleared with loss of transformer TR#1	9	Stable	Stable
P1.03	3ph fault @ Churchtown 69 kV on 230/69 kV TR#3, normal cleared with loss of transformer TR#3	9	Stable	Stable
P1.04	3ph fault @ Churchtown 69 kV on Carneys Point - Pennsgrove circuit 0710, normal cleared with loss of Churchtown -Carneys Point - Pennsgrove 69 kV circuit 0710	9	Stable	Stable
P1.05	3ph fault @ Churchtown 69 kV on Quinton circuit 0723, normal cleared with loss of Churchtown - Quinton 69 kV circuit 0723	9	Stable	Stable
P1.06	3ph fault @ Churchtown 69 kV on Woodstown circuit 0725, normal cleared with loss of Churchtown - Woodstown 69 kV circuit 0725	9	Stable	Stable
P1.07	3ph fault @ Churchtown 69 kV on Woodstown circuit 0726, normal cleared with loss of Churchtown - Woodstown 69 kV circuit 0726	9	Stable	Stable
P1.08	3ph fault @ Churchtown 69 kV on Salem circuit 0724, normal cleared with loss of Churchtown - Salem 69kV circuit 0724	9	Stable	Stable
P1.09	3ph fault @ Churchtown 69 kV on Beckett - Paulsboro circuit 0722, normal cleared with loss of Churchtown - Beckett – Paulsboro 69kV circuit 0722	9	Stable	Stable
P1.10	3ph fault @ Churchtown 138 kV on Upper Pittsgrove circuit 1405, normal cleared with loss of Churchtown - Upper Pittsgrove circuit 1405	9	Stable	Stable
P1.11	3ph fault @ Churchtown 138 kV on 230/138 kV TR#4, normal cleared with loss of Churchtown 230/138 kV TR#4	9	Stable	Stable
P1.12	3ph fault @ Churchtown 230 kV on Orchard circuit 2309, normal cleared with loss of Churchtown - Orchard circuit 2309	7	Stable	Stable
P1.13	3ph fault @ Churchtown 230 kV on Chambers circuit 2313, normal cleared with loss of Churchtown - Chambers circuit 2313	7	Stable	Stable

Fault ID	Fault description	Clearing Time & Reclose (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P1.14	3ph fault @ Churchtown 230 kV on 230/69 kV TR#1, normal cleared with loss of Churchtown 230/69 kV transformer TR#1	7	Stable	Stable
P1.15	3ph fault @ Churchtown 230 kV on 230/69 kV TR#3, normal cleared with loss of Churchtown 230/69 kV transformer TR#3	7	Stable	Stable
P1.16	3ph fault @ Churchtown 230 kV on 230/138 kV TR#4, normal cleared with loss of Churchtown 230/138 kV transformer TR#4	7	Stable	Stable
P1.17	3ph fault @ Pennsgrove 69 kV on Carneys Point - Churchtown circuit 0710, normal cleared with loss of Churchtown -Carneys Point - Pennsgrove 69 kV circuit 0710	9	Stable	Stable
P1.18	3ph fault @ Pennsgrove 69 kV on Oldman circuit 0704, normal cleared with loss of Oldman - Pennsgrove 69 kV circuit 0704	9	Stable	Stable
P1.19	3ph fault @ Quinton 69 kV on Churchtown circuit 0723, normal cleared with loss of Churchtown - Quinton 69 kV circuit 0723	9	Stable	Stable
P1.20	3ph fault @ Quinton 69 kV on Roadstown circuit 0606, normal cleared with loss of Roadstown - Quinton 69 kV circuit 0606	9	Stable	Stable
P1.21	3ph fault @ Woodstown 69 kV on Churchtown circuit 0725, normal cleared with loss of Churchtown - Woodstown 69 kV circuit 0725	9	Stable	Stable
P1.22	3ph fault @ Woodstown 69 kV on Churchtown circuit 0726, normal cleared with loss of Churchtown - Woodstown 69 kV circuit 0726	9	Stable	Stable
P1.23	3ph fault @ Woodstown 69 kV on Mannington Mills – Salem circuit 0745, normal cleared with loss of Mannington Mills – Salem - Woodstown 69 kV circuit 0745, and Mannington Mills generation units	9	Stable	Stable
P1.24	3ph fault @ Woodstown 69 kV on High Street circuit 0765, normal cleared with loss of High Street - Woodstown 69 kV circuit 0765	9	Stable	Stable
P1.25	3ph fault @ Woodstown 69 kV on Clayton circuit 0714, normal cleared with loss of Clayton - Woodstown 69 kV circuit 0714	9	Stable	Stable
P1.26	3ph fault @ Woodstown 69 kV on Laurel circuit 0740, normal cleared with loss of Laurel - Woodstown 69 kV circuit 0740	9	Stable	Stable
P1.27	3ph fault @ Paulsboro 69 kV on Beckett - Churchtown circuit 0722, normal cleared with loss of Churchtown - Beckett – Paulsboro 69kV circuit 0722	9	Stable	Stable
P1.28	3ph fault @ Paulsboro 69 kV on High Street circuit 0605, normal cleared with loss of High Street – Paulsboro 69kV circuit 0605	9	Stable	Stable

Table 6: Single-phase Faults with Stuck Breaker – Category P4

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P4_1B 1.01	SLG @ Churchtown on AE1-115 69 kV circuit. Breaker stuck at Churchtown. Normal cleared with loss of AE1-115 generation unit; delay cleared with loss of Churchtown 69 kV bus tie.	9/24	Stable	Stable
P4_1B 1.02	SLG @ Churchtown on AE1-115 69 kV circuit. Breaker AW stuck at Churchtown. Normal cleared with loss of AE1-115 generation unit; delay cleared with loss of Churchtown 230/69 kV transformer T1.	9/24	Stable	Stable
P4_1B 1.03	SLG @ Churchtown 69 kV on 230/69 kV TR#1, Breaker D stuck at Churchtown. Normal cleared with loss of 230/69 kV TR#1; delay cleared with no additional element loss.	9/24	Stable	Stable
P4_1B 1.04	SLG @ Churchtown 69 kV on Carneys Point - Pennsgrove circuit 0710, Breaker W stuck at Churchtown. Normal cleared with loss of Carneys Point - Pennsgrove circuit 0710; delay cleared with loss of Churchtown - Carneys Point circuit 0710 and Churchtown 230/69 kV TR#1.	9/24	Stable	Stable
P4_1B 1.05	SLG @ Churchtown 69 kV on Carneys Point - Pennsgrove circuit 0710, Breaker Y stuck at Churchtown. Normal cleared with loss of Carneys Point - Pennsgrove circuit 0710; delay cleared with loss of Churchtown - Carneys Point circuit 0710.	9/24	Stable	Stable
P4_1B 1.06	SLG @ Churchtown 69 kV on Quinton circuit 0723, Breaker CU stuck at Churchtown. Normal cleared with loss of Churchtown - Quinton circuit 0723; delay cleared with loss of Churchtown 230/69 kV TR#3.	9/24	Stable	Stable
P4_1B 1.07	SLG @ Churchtown 69 kV on Quinton circuit 0723, Breaker IO stuck at Churchtown. Normal cleared with loss of Churchtown - Quinton circuit 0723; delay cleared with loss of Churchtown 69 kV bus tie.	9/24	Stable	Stable
P4_1B 1.08	SLG @ Churchtown 69 kV on Woodstown circuit 0725, Breaker LM stuck at Churchtown. Normal cleared with loss of Churchtown - Woodstown circuit 0725; delay cleared with loss of Churchtown 69 kV bus tie.	9/24	Stable	Stable
P4_1B 1.09	SLG @ Churchtown 69 kV on Woodstown circuit 0725, Breaker JN stuck at Churchtown. Normal cleared with loss of Churchtown - Woodstown circuit 0725; delay cleared with loss of Churchtown 69/12 kV TR#5.	9/24	Stable	Stable
P4_1B 1.10	SLG @ Churchtown 69 kV on Woodstown circuit 0726, Breaker HP stuck at Churchtown. Normal cleared with loss of Churchtown - Woodstown circuit 0726; delay cleared with loss of Churchtown 69/12 kV TR#5.	9/24	Stable	Stable
P4_1B 1.11	SLG @ Churchtown 69 kV on Woodstown circuit 0726, Breaker GQ stuck at Churchtown. Normal cleared with loss of Churchtown - Woodstown circuit 0726; delay cleared with loss of Churchtown - Beckett - Paulsboro circuit 0722.	9/24	Stable	Stable

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P4_1B 1.12	SLG @ Churchtown 69 kV on Beckett - Paulsboro circuit 0722, Breaker GQ stuck at Churchtown. Normal cleared with loss of Churchtown - Beckett - Paulsboro circuit 0722; delay cleared with loss of Churchtown - Woodstown circuit 0726.	9/24	Stable	Stable
P4_1B 1.13	SLG @ Churchtown 69 kV on Beckett - Paulsboro circuit 0722, Breaker ES stuck at Churchtown. Normal cleared with loss of Churchtown - Beckett - Paulsboro circuit 0722; delay cleared with loss of Churchtown - Salem circuit 0724.	9/24	Stable	Stable
P4_1B 1.14	SLG @ Churchtown 69 kV on Salem circuit 0724, Breaker ES stuck at Churchtown. Delay cleared with loss of Churchtown - Salem circuit 0724, and Churchtown - Beckett - Paulsboro circuit 0722.	9/24	Stable	Stable
P4_1B 1.15	SLG @ Churchtown 69 kV on Salem circuit 0724, Breaker DT stuck at Churchtown. Delay cleared with loss of Churchtown - Salem circuit 0724, and Churchtown 230/69 kV TR#3.	9/24	Stable	Stable
P4_1B 1.16	SLG @ Churchtown 138 kV on Upper Pittsgrove circuit 1405, Breaker BB stuck at Churchtown. Normal cleared with loss of Churchtown - Upper Pittsgrove circuit 0722; delay cleared with loss of Churchtown 230/138 kV TR#4.	9/23	Stable	Stable
P4_1B 1.17	SLG @ Churchtown 230 kV on Orchard circuit 2309, Breaker F stuck at Churchtown. Normal cleared with loss of Churchtown - Orchard circuit 2309; delay cleared with no additional element loss.	7/18.5	Stable	Stable
P4_1B 1.18	SLG @ Churchtown 230 kV on Orchard circuit 2309, Breaker C stuck at Churchtown. Normal cleared with loss of Churchtown - Orchard circuit 2309; delay cleared with loss of Churchtown - Chambers circuit 2313.	7/18.5	Stable	Stable
P4_1B 1.19	SLG @ Churchtown 230 kV on Chambers circuit 2313, Breaker A stuck at Churchtown. Normal cleared with loss of Churchtown - Chambers circuit 2313; delay cleared with no additional element loss.	7/18.5	Stable	Stable
P4_1B 1.20	SLG @ Churchtown 230 kV on Chambers circuit 2313, Breaker C stuck at Churchtown. Normal cleared with loss of Churchtown - Chambers circuit 2313; delay cleared with loss of Churchtown - Orchard circuit 2309.	7/18.5	Stable	Stable
P4_1B 1.21	SLG @ Churchtown 230 kV on 230/138 kV TR#4, Breaker E or B stuck at Churchtown. Normal cleared with loss of Churchtown 230/138 kV TR#4; delay cleared with no additional element loss.	7/18.5	Stable	Stable
P4_1B 1.22	SLG @ Churchtown 230 kV on 230/69 kV TR#1, Breaker U stuck at Churchtown. Normal cleared with loss of Churchtown 230/69 kV TR#1; delay cleared with no additional element loss.	7/18.5	Stable	Stable
P4_1B 1.23	SLG @ Churchtown 230 kV on 230/69 kV TR#1, Breaker P stuck at Churchtown. Normal cleared with loss of Churchtown 230/69 kV TR#1; delay cleared with no additional element loss.	7/18.5	Stable	Stable

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P4_1B 1.24	SLG @ Pennsgove 69 kV on Oldman circuit 0704, Breaker A stuck at Pennsgove. Normal cleared with loss of Pennsgove - Oldman circuit 0704; delay cleared with loss of Pennsgrove station.	9/24	Stable	Stable
P4_1B 1.25	SLG @ Quinton 69/12 kV T2. Breaker N stuck at Quinton. Delay cleared with loss of Quinton – Churchtown circuit 0723, Quinton reactor, and Quinton 69/12 kV T2.	9/24	Stable	Stable
P4_1B 1.26	SLG @ Quinton 69 kV on Roadstown circuit 0606. Breaker H stuck at Quinton. Normal cleared with loss of Quinton - Roadstown circuit 0606; delay cleared with loss of Quinton generation units, and Quinton 69/12 kV T1.	9/24	Stable	Stable
P4_1B 1.27	SLG @ Woodstown 69 kV on Mannington Mills – Salem circuit 0745. Breaker W stuck at Woodstown. Delay cleared with loss of Woodstown - Mannington Mills – Salem circuit 0745, Woodstown – Churchtown 0726, High Street - Woodstown 69 kV circuit 0765, Woodstown – Laurel 69 kV circuit 0740, Woodstown bus tie, Mannington Mills's generation units, and V2-046 generation units.	9/24	Stable	Stable
P4_1B 1.28	SLG @ Woodstown 69 kV on Clayton circuit 0714. Breaker F stuck at Woodstown. Normal cleared with loss of Woodstown - Clayton circuit 0714; delay cleared with loss of Woodstown – Churchtown 0725, Woodstown bus tie, Woodstown 69/12 kV Transformer T4, and Woodstown Capacitors.	9/24	Stable	Stable
P4_1B 1.29	SLG @ Paulsboro 69 kV on High Street circuit 0605. Breaker L stuck at Paulsboro. Normal cleared with loss of Paulsboro - High Street circuit 0605; delay cleared with loss of Paulsboro – Mickleton circuit 0746, Paulsboro 69 kV bus tie.	9/24	Stable	Stable

Table 7: Single-phase Faults with Delayed (Zone 2) Clearing due to Primary Communication/Relay Failure – Category P5

Fault ID	Fault description	Clearing Time (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P5.01	SLG @ 80% of 69 kV circuit from Churchtown to AE1-115, Trips AE1-115	9/42	Stable	Stable
P5.02	SLG @ 80% of 69 kV circuit 0710 from Churchtown to Carneys Point - Pennsgrove	9/42	Stable	Stable
P5.03	SLG @ 80% of 69 kV circuit 0723 from Churchtown to Quinton	9/42	Stable	Stable
P5.04	SLG @ 80% of 69 kV circuit 0725 from Churchtown to Woodstown	9/42	Stable	Stable
P5.05	SLG @ 80% of 69 kV circuit 0726 from Churchtown to Woodstown	9/42	Stable	Stable

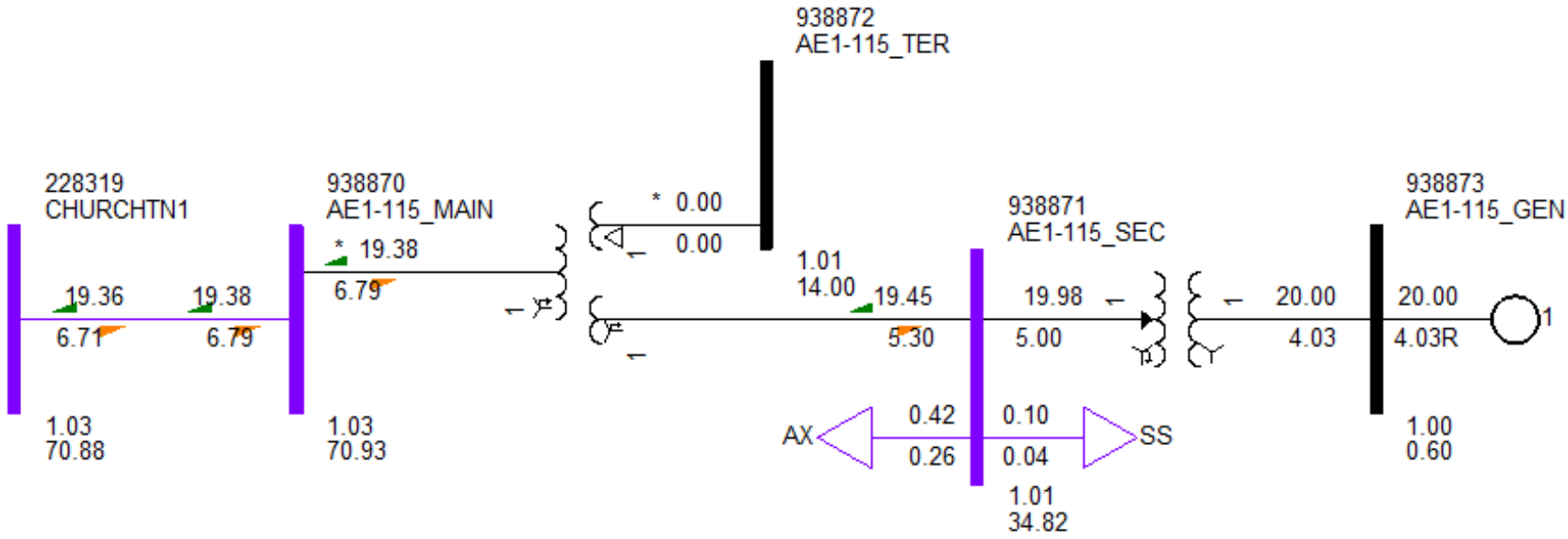
Fault ID	Fault description	Clearing Time (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P5.06	SLG @ 80% of 69 kV circuit 0722 from Churchtown to Beckett - Paulsboro	9/42	Stable	Stable
P5.07	SLG @ 80% of 138 kV circuit 1405 from Churchtown to Upper Pittsgrove	9/41	Stable	Stable
P5.08	SLG @ 80% of 230 kV circuit 2309 from Churchtown to Orchard	7/38	Stable	Stable
P5.09	SLG @ 80% of 230 kV circuit 2313 from Churchtown to Chambers	7/38	Stable	Stable
P5.10	SLG @ 80% of 69 kV circuit 0704 from Pennsgrove to Oldman	9/42	Stable	Stable
P5.11	SLG @ 80% of 69 kV circuit 0722 from Quinton to Roadstown	9/42	Stable	Stable
P5.12	SLG @ 80% of 69 kV circuit 0606 from Woodstown to High Street	9/42	Stable	Stable
P5.13	SLG @ 80% of 69 kV circuit 0714 from Woodstown to Clayton	9/42	Stable	Stable
P5.14	SLG @ 80% of 69 kV circuit 0740 from Woodstown to Laurel	9/42	Stable	Stable
P5.15	SLG @ 80% of 69 kV circuit 0605 from Paulsboro to High Street	9/42	Stable	Stable

Table 8: Single-phase Faults with Normal Clearing on Common Structure – Category P7

Fault ID	Fault description	Clearing Time (Cycles)	AE1-115 No Mitigation	AE1-115 with AB1-169A Mitigation
P7.01	CONTINGENCY 'AE_P7-1 AE9TOWER' CHURCH TO UPITTS 138 KV and CHURCH TO ORCHARD 230 KV	9.0/7.0	Stable	Stable
P7.02	CONTINGENCY 'AE_P7-1 AE10TOWER' FRANK TO LANDIS 138 KV and MONROE TO LANDIS 138 KV	9.0	Stable	Stable
P7.03	CONTINGENCY 'AE_P7-1 AE11TOWER' CHURCH TO UPPITTS 138 KV and ORCH TO CARD 230 KV	9.0/7.0	Stable	Stable
P7.04	CONTINGENCY 'AE_P7-1 AE12TOWER' UPPITTS TO LANDIS 138 KV and ORCH TO CARD 230 KV	9.0/7.0	Stable	Stable
P7.05	CONTINGENCY 'AE_P7-1 AE13TOWER' LANDIS TO MINO 138 KV and ORCH TO CARD 230 KV	9.0/7.0	Unstable	Stable*

* with AB1-169A mitigation measures.

PSS/E Model One Line Diagram



E1-115 PSS/E Dynamic Model

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/*********************************************
/*** AE1-115 – 20.0 MW MFO
/*** POI at Churchtown 69 kV substation
/*** Directly connection to the substation
/*********************************************

/*****************************************************************************
*********
/ PSSE Version 33
/*****************************************************************************
*********

/
938873 'USRMDL'  1  'REGCAU1'  101  1  1  14  3  4  1
    0.0200      1.4000      0.90000     0.50000     1.00000
    1.2000      0.0500      0.01000    -1.0         0.01000
    0.0000      20.000     -20.0000     0.7000 /
938873 'USRMDL' 1 'REECCU1' 102 0 5 45 7 6
    938870    0    1    0    0
    0.9000      1.1000      0.0100    -0.100          0.1000
    2.0000      1.0         -1.0       0.0000         0.05
    0.6         -0.6         1.20      0.8            1.0
    1.00        1.000        1.00      0.46           1.0
   -1.00        1.00        -1.00      1.00           0.46
          0.00       1.0         0.33        1.0        0.66
          1.0        1.0         1.0         0.0        1.0
          0.33       1.0         0.66        1.0        1.0
          1.00     9999.0         0.85        1.0        0.2  /
938873 'USRMDL' 1 'REPCAU1' 107 0 7 27 7 9
    938870    938870    228319    '1'    0    1    0
    0.04        0.0         0.5       0.0           0.04
    0.88      0.0019          0.007     0.04          999.0
   -999.0       0.0         0.0       0.6           -0.6
    0.0         0.5         0.04      0.0           0.0
    999         -999        1.0       0.0           0.04
    0.04        0.04 /
/
93887301 'VTGTPAT' 938873 938873  '1' -1.0000  1.2000  0.0080  0.0000  /
93887302 'VTGTPAT' 938873 938873  '1' -1.0000  1.1800  0.2080  0.0000  /
93887303 'VTGTPAT' 938873 938873  '1' -1.0000  1.1500  0.5080  0.0000  /
93887304 'VTGTPAT' 938873 938873  '1' -1.0000  1.1100  1.0080  0.0000  /
93887305 'VTGTPAT' 938873 938873  '1' -1.0000  1.1000  5000.0  0.0000  /
93887306 'VTGTPAT' 938873 938873  '1' 0.44000  5.0000  0.1580  0.0000  /
93887307 'VTGTPAT' 938873 938873  '1' 0.64000  5.0000  0.3080  0.0000  /
93887308 'VTGTPAT' 938873 938873  '1' 0.74000  5.0000  2.0080  0.0000  /
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93887309 'VTGTPAT' 938873 938873 '1' 0.85000 5.0000 3.0080 0.0000 /
93887310 'FRQTPAT' 938873 938873 '1' 57.8000 61.800 0.1080 0.0300 /
93887311 'FRQTPAT' 938873 938873 '1' 58.4000 61.400 30.008 0.0300 /
93887312 'FRQTPAT' 938873 938873 '1' 58.8000 61.000 120.008 0.0300 /
93887313 'FRQTPAT' 938873 938873 '1' 59.5000 60.500 2000.0 0.0300 /
/**
/*** Project: AE1-115 ends

AE1-115 PSS/E Case Dispatch

Bus Number	Bus Name	Id	Vsched (pu)	Remote Bus	In Service	PGen (MW)	PMax (MW)	PMin (MW)	QGen (Mvar)	QMax (Mvar)	QMin (Mvar)	Mbase (MVA)
200036	SALEM-G1 25.000	1	1.0500	200014	1	1253.0000	1253.0000	0.0000	355.9068	570.8710	100.0000	1300.00
200037	SALEM-G2 25.000	1	1.0500	200014	1	1245.0000	1245.0000	1002.8490	355.9068	547.7290	100.0000	1300.00
200062	SALEM G3 22.000	1	1.0000	0	1	38.4000	38.4000	0.0000	-14.0000	14.0000	-14.0000	100.00
227999	CARDSVC 16.000	1	1.0100	0	1	0.0000	0.0000	0.0000	-13.9099	150.0000	-100.0000	100.00
228200	CARL#1CT 13.800	1	1.0300	0	1	37.8000	37.8000	32.8860	-2.2000	6.0500	-2.2000	46.50
228201	CARL#2CT 13.800	1	1.0300	0	1	40.0000	40.0000	34.8000	0.0000	0.0000	0.0000	46.50
228203	P06 13.800	1	1.0100	0	1	100.0000	100.0000	92.0000	-14.0754	100.0000	-55.0000	105.10
228306	PCLP STM 13.800	1	1.0317	0	1	60.2000	60.2000	34.1910	20.1919	45.0000	-59.0000	52.90
228307	PCLP GT 13.800	1	1.0317	0	1	60.1000	60.1000	0.0000	20.8138	29.2480	-25.0500	105.80
228309	CCLP NUG 23.000	1	1.0100	0	1	240.0000	240.0000	46.0000	80.7434	179.0000	-24.0000	335.00
228334	MANNMILG 4.1600	1	1.0145	0	1	2.8000	2.8000	0.0000	-0.1292	6.4860	-4.4100	3.85
228334	MANNMILG 4.1600	2	1.0145	0	1	2.8000	2.8000	0.0000	-0.1292	6.4860	-4.4100	3.85
228334	MANNMILG 4.1600	3	1.0145	0	1	2.8000	2.8000	0.0000	-0.1292	6.4860	-4.4100	3.85
228343	QUINTN#1 12.900	1	1.0000	0	1	2.0000	2.0000	0.0000	0.0000	0.0000	0.0000	2.00
228351	V2-046C 12.900	1	1.0000	0	1	7.0000	7.0000	0.0000	0.0000	0.0000	0.0000	7.00
228357	V2-046E 12.900	1	1.0000	0	1	12.9000	12.9000	12.9000	0.0000	0.0000	0.0000	12.90
924531	AB2-102 GEN 18.000	1	1.0217	228207	1	236.5000	236.5000	0.0000	92.3794	140.0000	-100.0000	273.00
938873	AE1-115_GEN 0.6000	1	1.0000	0	1	20.0000	20.0000	-20.0000	-5.6465	11.2500	-11.2500	24.75