Generation Interconnection
Revised System Impact Study Report

For

PJM Generation Interconnection Request
Queue Position AB2-120

"Piney Grove-New Church 138 kV"

April 2017
Revised December 2020

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

The Interconnection Customer (IC), has proposed a 100 MW (38 MWC) solar generating facility to be located in Worcester County, Maryland. PJM studied the AB2-120 project as a tap of the Delmarva Power and Light's (DPL) Piney Grove-New Church 138 kV circuit and evaluated it for compliance with reliability criteria for summer peak conditions in 2020. The planned in-service date, as requested by the IC during the project kick-off call, is December 15, 2018. This date is not attainable due to required additional PJM studies and Transmission Owner construction schedules.

Point of Interconnection

The AB2-120 project will connect to the DPL transmission system at a new 138 kV three breaker ring bus substation to be constructed adjacent to the Piney Grove-New Church 138 kV circuit (see Attachment 1).

Transmission Owner Scope of Attachment Facilities Work

Substation Interconnection Estimate

Scope: Build a new 138 kV substation with a 3 position ring bus. Two of the positions on the ring bus will be transmission line terminals for the tie-in of Line 13764 to the substation. The other position will be a terminal configured for the interconnection of a generator.

Estimate: $4,300,000
Construction Time: 24 months

Major Equipment Included in Estimate:

- Control Enclosure, 20’ x 15’
  Qty. 1
- Power Circuit Breaker, 138 kV, 2000A, 40kA, 3 cycle
  Qty. 3
- Disconnect Switch, 138 kV, 2000A, Manual Wormgear, Arcing Horns
  Qty. 9
- CT/VT Combination Units, 138 kV
  Qty. 3
- CVT, 138 kV
  Qty. 6
- Disconnect Switch Stand, High, 138 kV, Steel
  Qty. 5
- Disconnect Switch Stand, Low, 138 kV, Steel
  Qty. 4
- CT/VT Stand, Single Phase, Low, 138 kV, Steel
  Qty. 3
- CVT Stand, Single Phase, Low, 138 kV, Steel
  Qty. 6
- SSVT, 138 kV/240-120 V
  Qty. 1
- Relay Panel, Transmission Line, FL/BU (20”)
  Qty. 3
- Control Panel, 138 kV Circuit Breaker (10”)
  Qty. 3
- Take-off structure, 138 kV
  Qty. 2
- Bus Support Structure, 3 phase, 138 kV, Steel
  Qty. 8

Estimate Assumptions:

- Land purchase for the substation is not included.
- A 3.0 acre, relatively square lot is available for use.
- Site clearing and grading performed by Developer.
- Lightning protection (lightning masts) are not required.

Required Relaying and Communications
New protection relays are required for the new terminals.

Protective Relay Requirements

An SEL-487 will be required for primary protection and an SEL-387 will be required for back-up protection for the generator POI terminal. One 20" relay panel for each line terminal will be required for front line and back-up protection.

New protection relays are required for the new line terminals. An SEL-421 will be required for primary protection and an SEL-311C will be required for back-up protection. A 20" relay panel will be required for each transmission line terminal (2 total).

An SEL-451 relay on a 20" breaker control panel will be required for the control and operation of each new 138 kV circuit breaker.

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

The cost of the required relay and communications is included in the Substation Interconnection Estimate.

Communications Requirements

The protective relay schemes will require diverse paths out of the new 138 kV substation between Piney Grove Substation and New Church Substation. The construction of the new 138 kV substation will require installing OPGW fiber on the 138 kV line from Piney Grove Substation to New Church Substation. The estimated cost to perform this work is **$3,900,000** and will take approximately **36 months** to complete.

Metering

Three phase 138 kV revenue metering points will need to be established. DPL will purchase and install all metering instrument transformers as well as construct a metering structure. The secondary wiring connections at the instrument transformers will be completed by DPL's metering technicians. The metering control cable and meter cabinets will be supplied and installed by DPL. DPL will install conduit for the control cable between the instrument transformers and the metering enclosure. The location of the metering enclosure will be determined in the construction phase. DPL will provide both the Primary and the Backup meters. DPL's meter technicians will program and install the Primary & Backup solid state multi-function meters for each new metering position. Each meter will be equipped with load profile, telemetry, and DNP outputs. The IC will be provided with one meter DNP output for each meter. DPL will own the metering equipment for the interconnection point, unless the IC asserts its right to install, own, and operate the metering system.

The Interconnection Customer will be required to make provisions for a voice quality phone line within approximately 3 feet of each Company metering position to facilitate remote interrogation and data collection.

It is the IC's responsibility to send the data that PJM and DPL requires directly to PJM. The IC will grant permission for PJM to send DPL the following telemetry that the IC sends to PJM: real time MW, MVAR, volts, amperes, generator status, and interval MWH and MVARH.

The estimate for DPL to design, purchase, and install metering as specified in the aforementioned scope for metering is included in the Substation Interconnection Estimate.

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.

Summer Peak Analysis - 2020

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

Steady-State Voltage Requirements

No issues identified.

Short Circuit

No issues identified.

Stability and Reactive Power Requirement

No issued identified. See Attachment 2 for details.

Light Load Analysis - 2020

Light Load analysis is not required for AB2-120.

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.

1. (PECO - PECO) The LINWOOD-CHICHST1 230 kV line (from bus 213750 to bus 213489 ckt 1) loads from 96.39% to 97.26% (AC power flow) of its emergency rating (1593 MVA) for the single line contingency outage of '220-39'. This project contributes approximately 16.3 MW to the thermal violation.

CONTINGENCY '220-39' /* $ DELCO $ 220-39 $ L
TRIP BRANCH FROM BUS 213490 TO BUS 213750 CKT 1 /*
END

2. (PECO - PECO) The LINWOOD-CHICHST2 230 kV line (from bus 213750 to bus 213490 ckt 1) loads from 96.4% to 97.27% (AC power flow) of its emergency rating (1593 MVA) for the single line contingency outage of '220-43/* $ DELCO $ 220-43 $ L'. This project contributes approximately 16.27 MW to the thermal violation.

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CONTINGENCY '220-43/* $ DELCO $ 220-43 $ L'
  TRIP BRANCH FROM BUS 213489 TO BUS 213750 CKT 1              /*
  END/*          $ DELCO $ 220-43 $ L
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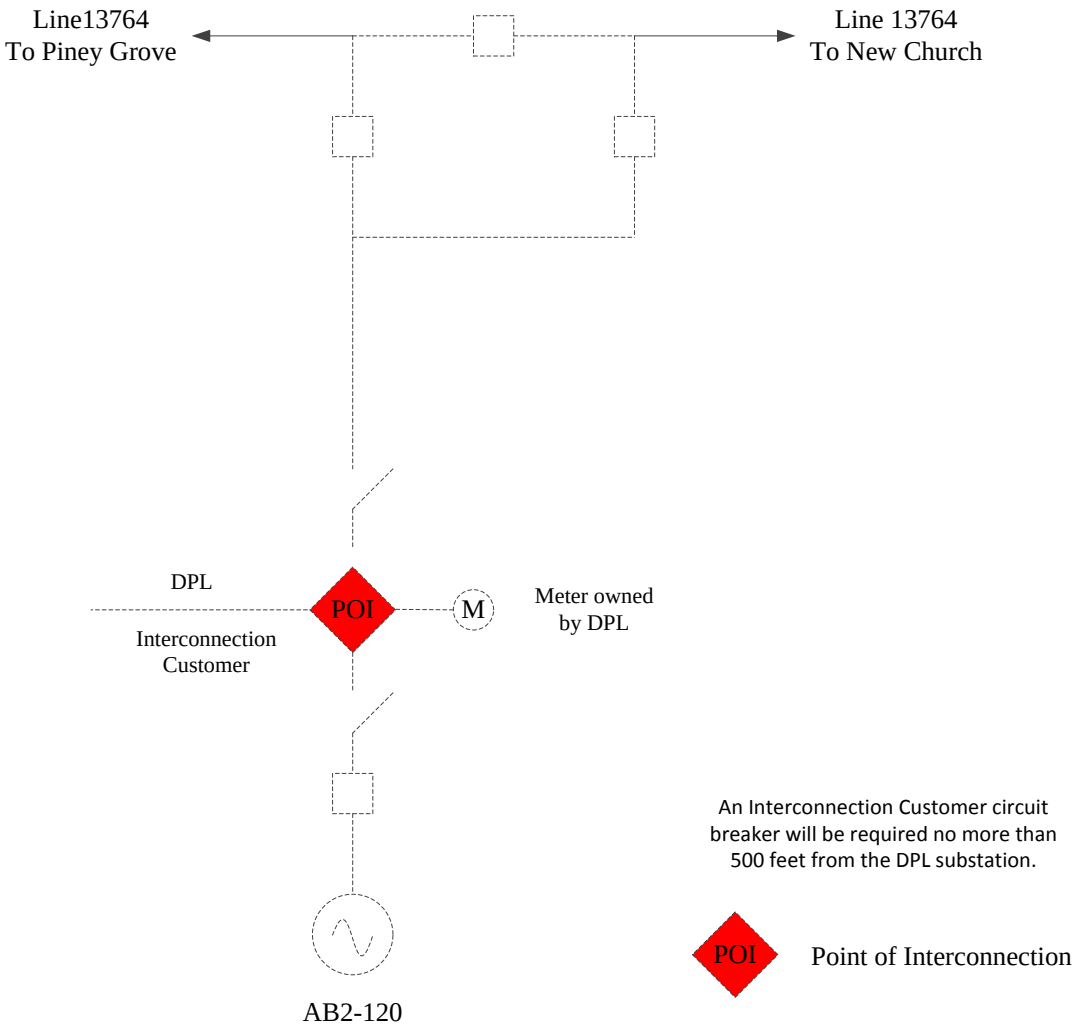
Delmarva Power and Light Costs

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 DPL in connection with the AB2-120 project. DPL reserves the right to reassess issues presented in this document and, upon appropriate justification, submit additional costs related to the AB2-120 project.

Attachment 1 – Single Line Diagram

AB2-120
Piney Grove – New Church 138 kV
New 138 kV Substation



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Attachment 2

AB2-120 System Impact Study

Dynamic Simulation Analysis

Executive Summary

Generator Interconnection Request AB2-120 is for a 100 MW Maximum Facility Output (MFO) solar generation plant. AB2-120 consists of 54 x Solar GE 2.0 2.0 MVA inverters with a Point of Interconnection (POI) at a tap of New Church – Piney Grove 138 kV circuit, in the Delmarva Power and Light Company (DPL) transmission system, Worcester County, Maryland.

This report describes a dynamic simulation analysis of AB2-120 as part of the overall system impact study.
The load flow scenarios for the analysis were based on the RTEP 2020 Peak Load case, modified to include applicable queue projects. AB2-120 was set to maximum power output.
AB2-120 was tested for compliance with NERC, PJM, Transmission Owner and other applicable criteria. 49 contingencies were studied, each with at least a 20 second simulation time period. Studied scenarios included:

a) Steady state operation (30 second simulation);

b) Three-phase faults with normal clearing time;

c) Single-phase faults with 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.

No relevant Bus, Tower or High Speed Reclosing (HSR) 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.
For the all 49 fault contingencies tested on the 2020 peak load case:

a) AB2-120 is able to ride through the faults (except for faults where protective action trips a generator(s)),

b) The system with AB2-120 included is transiently stable and post-contingency oscillations are 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.

No mitigations were found to be required.

1. Introduction

Generator Interconnection Request AB2-120 is for 100 MW Maximum Facility Output (MFO) solar generation plant. AB2-120 consists of 54 x Solar GE 2.0 2.0 MVA inverters with a Point of Interconnection (POI) at a tap of New Church – Piney Grove 138 kV circuit, in the Delmarva Power and Light Company (DPL) transmission system, Worcester County, Maryland.

This analysis is effectively a screening study to determine whether the addition of AB2-120 will meet the dynamics requirements of the NERC, PJM and Transmission Owner reliability standards.
In this report the AB2-120 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 AB2-120 is for 100 MW Maximum Facility Output (MFO) solar generation plant. AB2-120 consists of 54 x Solar GE 2.0 2.0 MVA inverters with a Point of Interconnection (POI) at a tap of New Church – Piney Grove 138 kV circuit, in the Delmarva Power and Light Company (DPL) transmission system, Worcester County, Maryland.

Figure 1 shows the simplified one-line diagram of the AB2-120 loadflow model. Table 1 lists the parameters given in the impact study data and the corresponding parameters of the AB2-120 loadflow model.
Additional project details are provided in Attachments 1 through 4:

- Attachment 1 contains the Impact Study Data which details the proposed AB2-120 project.
- Attachment 2 shows the one line diagram of the DPL system in the vicinity of AB2-120.
- Attachment 3 provides a diagram of the PSS/E model in the vicinity of AB2-120.
- Attachment 4 gives the PSS/E loadflow and dynamic models of the AB2-120 plant.

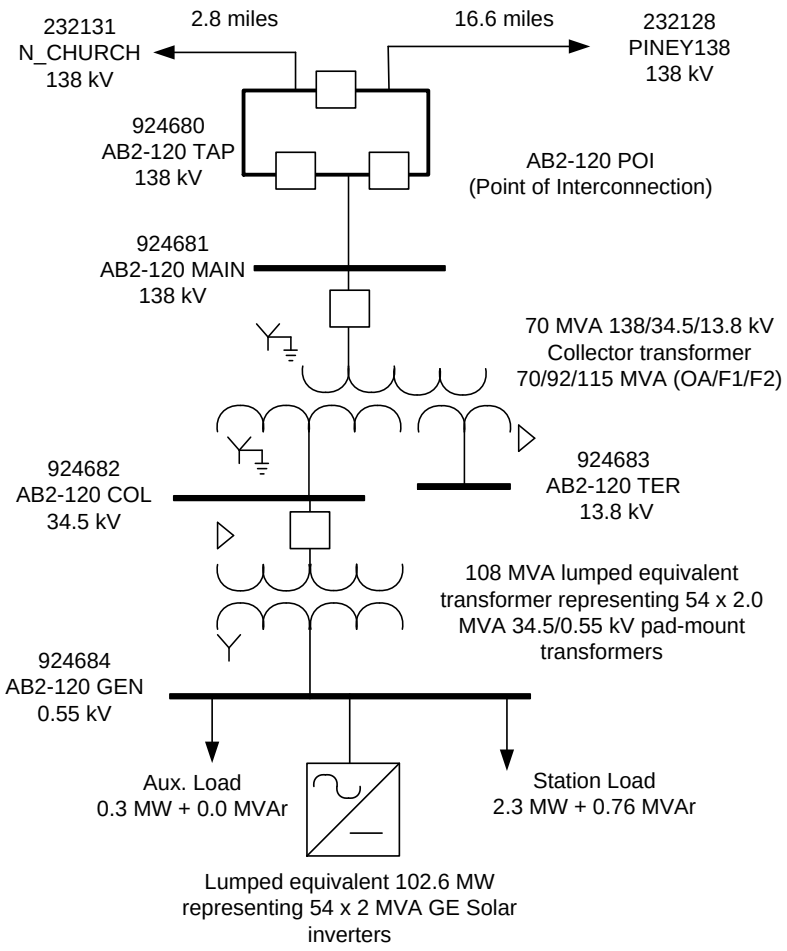

Figure 1: AB2-120 Plant Model

Table 1: AB2-120 Plant Model

	Impact Study Data	Model
Solar inverters	54 x 2 MVA GE 2.0 Solar inverters MVA base = 2.0 MVA Vt = 0.55 kV Unsaturated sub-transient reactance = N/A	Lumped equivalent representing 54 x 2 MVA GE 2.0 Solar inverters Pgen 102.6 MW Pmax 102.6 MW Pmin 0 MW Qgen -3.381 MVAr Qmax 33.723 MVAr Qmin -33.723 MVAr Mbase 108 MVA Zsorce j9999.0 pu @ Mbase
Solar inverter GSU transformers	54 x 34.5/0.55 kV two winding transformers Rating = 2.0 MVA Transformer base = 2.0 MVA Impedance = 0.0052 + j0.063 pu @ MVA base Number of taps = 5 Tap step size = 2.5 %	Lumped equivalent representing 54 x 34.5/0.55 kV two winding transformers Rating = 108 MVA Transformer base = 108 MVA Impedance = 0.0052 + j0.063 pu @ MVA base Number of taps = 5 Tap step size = 2.5 %
Collector step-up transformer	1 x 138/34.5/13.8 kV three winding transformer Rating = 70/92/115 MVA (OA/F1/F2) Transformer base = 70 MVA Impedances: High to low = 0.002 + j0.08 pu High to tertiary = 0.0017 + j0.135 pu Low to tertiary = 0.0021 + j0.045 pu All impedances @ MVA base Number of taps = 5 Tap step size = 2.5%	1 x 138/34.5/13.8 kV three winding transformer Rating = 70/92/115 MVA (OA/F1/F2) Transformer base = 70 MVA Impedances: High to low = 0.002 + j0.08 pu High to tertiary = 0.0017 + j0.135 pu Low to tertiary = 0.0021 + j0.045 pu All impedances @ MVA base Number of taps = 5 Tap step size = 2.5%
Auxiliary load	0.3 MW + 0.0 MVAr	0.3 MW + 0.0 MVAr at low voltage side of GSU
Station load	2.3 MW + 0.76 MVAr	2.3 MW + 0.76 MVAr at low voltage side of GSU

Transmission line	N/A	Modeled as zero impedance line

3. Loadflow and Dynamics Case Setup

The dynamics simulation analysis was carried out using PSS/E Version 33.7.0.
The load flow scenarios and fault cases for this study are based on PJM's Regional Transmission Planning Process[1] and discussions with PJM.
The selected load flow scenarios were the RTEP 2020 peak load case with the following modifications:

a) Addition of all applicable queue projects prior to AB2-120.

b) Addition of AB2-120 queue project.

c) Removal of withdrawn and subsequent queue projects in the vicinity of AB2-120.

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

e) Merchant transmission projects X3-028 and S57/S58 set online and at maximum power import into PJM.

The AB2-120 initial conditions are listed in Table 2, indicating maximum power output.

Table 2: AB2-120 initial conditions

Bus	Name	Unit	PGEN (MW)	QGEN (MVar)	ETERM (pu)	POI Voltage (pu)
924684	AB2-120 GEN	1	102.6 MW	-5.0708	1	1.0172

Generation within the PJM500 system (area 225 in the PSS/E case) and within the vicinity of AB2-120 was dispatched online at maximum output (PMAX). The dispatch of generation in the vicinity of AB2-120 is given in Attachment 5.

[1] 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

Table 3 to Table 6 list the contingencies that were studied, with representative worst case total clearing times provided by PJM. Each contingency was studied over at least a 20 second simulation time interval.
The studied contingencies include:

a) Steady state operation (30 second);

b) Three phase faults with normal clearing time;

c) Single phase faults with stuck breaker;

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.

No relevant bus, tower or high speed reclosing (HSR) contingencies were found.
Buses at which the faults listed above will be applied are:

- AB2-120 POI 138 kV
- Piney Grove 138 kV
- New Church 138 kV

The one line diagram of the DPL network in the vicinity of AB2-120 is included in Attachment 2.
Actual clearing times provided by the TO were used for this study.
The positive sequence fault impedances for single line to ground faults were derived from the AB2 Impact Short Circuit case by using the SCMU fault calculation method.

5. Evaluation Criteria

This study is focused on AB2-120, 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:

a) AB2-120 is able to ride through the faults (except for faults where protective action trips a generator(s)),

b) The system with AB2-120 included should be transiently stable and post-contingency oscillations are 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.

6. Summary of Results

Plots from the dynamic simulations are provided in Attachment 6 with results summarized in Table 3 to Table 6.

All fault contingencies tested on the 2020 Peak Load case met the recovery criteria:

a) AB2-120 is able to ride through the faults (except for faults where protective action trips a generator(s)),

b) The system with AB2-120 included is transiently stable and post-contingency oscillations are 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.

7. Recommendations and Mitigations

No adverse impacts attributable to the queue project under study were found and as such, no mitigations were found to be required.

Table 3: Steady State Operation

Fault ID	Duration	Result No mitigation
SS.01	Steady state 30 sec	Stable

Table 4: Three-phase Faults with Normal Clearing

Fault ID	Fault description	Clearing Time (Cycles)	Result No Mitigation
3N.01	Fault at AB2-120 POI 138 kV on AB2-120 circuit resulting in additional loss of AB2-120.	5.75	Stable
3N.02	Fault at AB2-120 POI 138 kV on Piney Grove circuit	5.75	Stable
3N.03	Fault at AB2-120 POI 138 kV on New Church circuit	5.75	Stable
3N.04	Fault at Piney Grove 138 kV on AB2-120 POI circuit	5.75	Stable
3N.05	Fault at Piney Grove 138 kV on Loretto circuit (13777)	5.75	Stable
3N.06	Fault at Piney Grove 138 kV on Piney Grove 230/138 kV Transformer AT20	5.75	Stable
3N.07	Fault at Piney Grove 138 kV on Piney Grove 138/69 kV Transformer AT1	5.75	Stable
3N.08	Fault at Piney Grove 138 kV on Wattsville circuit (13751)	5.75	Stable
3N.09	Fault at New Church 138 kV on AB2-120 POI circuit	5.75	Stable
3N.10	Fault at New Church 138 kV on Oak Hall circuit (13763)	5.75	Stable
3N.11	Fault at New Church 138 kV on Oak Hall circuit (13765)	5.75	Stable
3N.12	Fault at New Church 138 kV on New Church G1/G2 circuit resulting in additional loss of New Church G1 and G2.	5.75	Stable
3N.13	Fault at New Church 138 kV on New Church G3/G4 circuit resulting in additional loss of New Church G3 and G4	5.75	Stable
3N.14	Fault at New Church 138 kV on New Church G5/G6/G7 circuit resulting in additional loss of New Church G5, G6 and G7)	5.75	Stable

Table 5: Single-Phase Faults With Stuck Breaker

Fault ID	Fault description	Clearing Time Primary and Delayed (Cycles)	Result No Mitigation
1B.01	Fault at AB2-120 POI 138 kV on AB2-120 circuit (resulting in additional loss of AB2-120). Breaker stuck to Piney Grove circuit. Fault cleared with loss of Piney Grover circuit.	5.75/20	Stable
1B.02	Fault at AB2-120 POI 138 kV on AB2-120 circuit (resulting in additional loss of AB2-120). Breaker stuck to New Church circuit. Fault cleared with loss of New Church circuit.	5.75/20	Stable
1B.03	Fault at AB2-120 POI 138 kV on Piney Grove circuit. Breaker stuck to AB2-120 POI circuit. Fault cleared with loss of AB2-120 POI circuit and additional loss of AB2-120.	5.75/20	Stable
1B.04	Fault at AB2-120 POI on Piney Grove circuit. Breaker stuck to New Church circuit. Fault cleared with loss of New Church circuit and additional loss of AB2-120.	5.75/20	Stable
1B.05	Fault at AB2-120 POI on New Church circuit. Breaker stuck AB2-120 POI circuit. Fault cleared with loss of AB2-120 POI circuit and additional loss of AB2-120.	5.75/20	Stable
1B.06	Fault at AB2-120 POI on New Church circuit. Breaker stuck to Piney Grove circuit. Fault cleared with loss of Piney Grove circuit and additional loss of AB2-120.	5.75/20	Stable
1B.07	Fault at Piney Grove 138 kV on AB2-120 POI circuit. Breaker stuck to Loretto circuit (13777). Fault cleared with loss of Loretto circuit (13777).	5.75/20	Stable
1B.08	Fault at Piney Grove 138 kV on AB2-120 POI circuit. Breaker stuck to Piney Grove 138/69 kV Transformer AT1. Fault cleared with loss of Piney Grove 138/69 kV Transformer AT1.	5.75/20	Stable
1B.09	Fault at Piney Grove 138 kV on Loretto circuit (13777). Breaker stuck to AB2-120 POI circuit. Fault cleared with loss of AB2-120 POI circuit.	5.75/20	Stable
1B.10	Fault at Piney Grove 138 kV on Loretto circuit (13777). Breaker stuck to Piney Grove 230/138 kV Transformer AT20. Fault cleared with loss of Piney Grove 230/138 kV Transformer AT20.	5.75/20	Stable
1B.11	Fault at Piney Grove 138 kV on Piney Grove 138/69 kV Transformer AT1. Breaker stuck to AB2-120 POI circuit. Fault cleared with loss of AB2-120 POI circuit.	5.75/20	Stable
1B.12	Fault at Piney Grove 138 kV on Piney Grove 138/69 kV Transformer AT1. Breaker stuck to Wattsville circuit (13751). Fault cleared with loss of Wattsville circuit.	5.75/20	Stable
1B.13	Fault at Piney Grove 138 kV on Piney Grove 230/138 kV Transformer AT20. Breaker stuck to Wattsville circuit (13751). Fault cleared with loss of Wattsville circuit.	5.75/20	Stable

Fault ID	Fault description	Clearing Time Primary and Delayed (Cycles)	Result No Mitigation
1B.14	Fault at Piney Grove 138 kV on Piney Grove 230/138 kV Transformer AT20. Breaker stuck to Loretto circuit (13777). Fault cleared with loss of Loretto circuit.	5.75/20	Stable
1B.15	Fault at Piney Grove 138 kV on Wattsville circuit (13751). Breaker stuck to Piney Grove 138/69 kV Transformer AT1. Fault cleared with loss of Piney Grove 138/69 kV Transformer AT1.	5.75/20	Stable
1B.16	Fault at Piney Grove 138 kV on Wattsville circuit (13751). Breaker stuck to Piney Grove 230/138 kV Transformer AT20. Fault cleared with loss of Piney Grove 230/138 kV Transformer AT20.	5.75/20	Stable
1B.17	Fault at New Church 138 kV on AB2-120 POI circuit. Breaker stuck to New Church G1/G2. Fault cleared with loss of New Church G1 and G2.	5.7512.75	Stable
1B.18	Fault at New Church 138 kV on AB2-120 POI circuit. Breaker stuck to New Church G3/G4. Fault cleared with loss of New Church G3 and G4.	5.75/12.75	Stable
1B.19	Fault at New Church 138 kV on New Church G1/G2 circuit. Breaker stuck to AB2-120 POI circuit. Fault cleared with loss of AB2-120 POI circuit.	5.75/20	Stable
1B.20	Fault at New Church 138 kV on New Church G1/G2 circuit. Breaker stuck to Oak Hall circuit (13763). Fault cleared with loss of Oak Hall circuit (13763).	5.75/20	Stable
1B.21	Fault at New Church 138 kV on Oak Hall circuit (13763). Breaker stuck to New Church G1/G2 circuit. Fault cleared with loss of New Church G1/G2 circuit, resulting in additional loss of New Church G1 and G2.	5.75/20	Stable
1B.22	Fault at New Church 138 kV on Oak Hall circuit (13763). Breaker stuck to New Church G5/G6/G7 circuit. Fault cleared with loss of New Church G5/G6/G7 circuit, resulting in additional loss of New Church G5, G6 and G7.	5.75/20	Stable
1B.23	Fault at New Church 138 kV on New Church G5/G6/G7 circuit. Breaker stuck to Oak Hall circuit (13763). Fault cleared with loss of Oak Hall circuit (13763).	5.75/20	Stable
1B.24	Fault at New Church 138 kV on New Church G5/G6/G7 circuit. Breaker stuck to Oak Hall circuit (13765). Fault cleared with loss of Oak Hall circuit (13765).	5.75/20	Stable
1B.25	Fault at New Church 138 kV on Oak Hall circuit (13765). Breaker stuck to New Church G5/G6/G7 circuit. Fault cleared with loss of New Church G5/G6/G7 circuit, resulting in additional loss of New Church G5, G6 and G7.	5.75/20	Stable
1B.26	Fault at New Church 138 kV on Oak Hall circuit (13765). Breaker stuck to New Church G3/G4 circuit. Fault cleared with loss of New Church G3/G4 circuit, resulting in additional loss of New Church G3 and G4.	5.75/20	Stable
1B.27	Fault at New Church 138 kV on New Church G3/G4 circuit. Breaker stuck to Oak Hall circuit (13765). Fault cleared with loss of Oak Hall circuit (13765).	5.75/20	Stable

Fault ID	Fault description	Clearing Time Primary and Delayed (Cycles)	Result No Mitigation
1B.28	Fault at New Church 138 kV on New Church G3/G4 circuit. Breaker stuck to AB2-120 POI circuit. Fault cleared with loss of AB2-120 POI circuit.	5.75/20	Stable

Table 6: Single-phase Faults With Delayed (Zone 2) Clearing at line end closest to AB2-120 POI

Fault ID	Fault description	Clearing Time Primary and Delayed (Cycles)	Result No Mitigation
1D.01	Fault at 80% of 138 kV line from AB2-120 POI to Piney Grove. Delayed clearing at AB2-120 POI.	5.75 / 37	Stable
1D.02	Fault at 80% of 138 kV line from AB2-120 POI to New Church. Delayed clearing at AB2-120 POI.	5.75 / 37	Stable
1D.03	Fault at 80% of 138 kV line from Piney Grove to Loretto (13777). Delayed clearing at Piney Grove.	5.75 / 37	Stable
1D.04	Fault at 80% of 138 kV line from Piney Grove to Wattsville circuit (13751). Delayed clearing at Piney Grove.	5.75 / 37	Stable
1D.05	Fault at 80% of 138 kV line from New Church to Oak Hall (13763). Delayed clearing at New Church.	5.75 / 37	Stable
1D.06	Fault at 80% of 138 kV line from New Church to Oak Hall (13765). Delayed clearing at New Church.	5.75 / 37	Stable