Generation Interconnection System Impact Study Report

For

PJM Generation Interconnection Request Queue Position AB2-037

"Keeney-Steele 230 kV"

April 2017
Revised: February 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

Cherrywood Solar 1, LLC, the Interconnection Customer (IC), has proposed a 202 MW (76.7 MWC) solar generating facility to be located in Caroline County, Maryland. PJM studied AB2-037 as a 202 MW injection into the Delmarva Power and Light Company (DPL) system at a tap of the Keeney-Steele 230 kV circuit and evaluated it for compliance with reliability criteria for summer peak conditions in 2020. The planned in-service date, as stated during the project kick-off call, is October 31, 2019.

The System Impact Study Report was revised and reissued in February 2020 to include the results from a restudy. The restudy was required due to projects withdrawing from the queue ahead of queue project AB2-037.

Point of Interconnection

The Interconnection Customer requested a transmission level interconnection. As a result, AB2-037 will interconnect with the DPL system at a new three breaker 230 kV ring bus substation to be constructed adjacent to the Keeney-Steele 230 kV circuit (see Attachment 1).

Transmission Owner Scope of Work

Substation Interconnection Estimate

Scope: Build a new 230 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 23009 to the substation. The other position will be a terminal configured for the interconnection of a generator.

Estimate: $6,491,000
Construction Time: 24 months

Major Equipment Included in Estimate:

• Control Enclosure, 20' x 15'	Qty. 1
• Power Circuit Breaker, 230 kV, 2000A, 40kA, 3 cycle	Qty. 3
• Disconnect Switch, 230 kV, 2000A, Manual Wormgear, Arcing Horns	Qty. 9
• CT/VT Combination Units, 230 kV	Qty. 3
• CVT, 230 kV	Qty. 6
• Disconnect Switch Stand, High, 230 kV, Steel	Qty. 5
• Disconnect Switch Stand, Low, 230 kV, Steel	Qty. 4
• CT/VT Stand, Single Phase, Low, 230 kV, Steel	Qty. 3
• CVT Stand, Single Phase, Low, 230 kV, Steel	Qty. 6
• SSVT, 230 kV/240-120 V	Qty. 1
• Relay Panel, Transmission Line, FL/BU (20")	Qty. 6
• Control Panel, 230 kV Circuit Breaker (10")	Qty. 3
• Take-off structure, 230 kV	Qty. 2
• Bus Support Structure, 3 phase, 230 kV, Steel	Qty. 8

Estimate Assumptions:

- Land purchase for the substation is not included.
- A 3.5 acre, relatively square lot is available for use.
- Site clearing and grading performed by Developer.
- Lightning protection (lightning masts) are not required.

<u>Required Relaying and Communications</u>
New protection relays are required for the new terminals.

An SEL-487 will be required for primary protection and an SEL-387 will be required for back-up protection. Two 20" relay panels for each generator terminal will be required for front line and back-up protection (2 total).

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. Two 20" relay panels will be required for each transmission line terminal (4 total).

An SEL-451 relay on a 20" breaker control panel will be required for the control and operation of each new 230 kV circuit breaker.

The project will require re-wiring and adjustment of existing relay schemes to accommodate the new 230 kV substation.

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

Metering

Three phase 230 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.

Interconnection Customer Scope of Work

The Interconnection Customer 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 DPL'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.

DPL Interconnection Customer Scope of Direct Connection Work Requirements:

- DPL requires that an IC circuit breaker is located within 500 feet of the new 230 kV substation to facilitate the relay protection scheme between DPL and the IC at the Point of Interconnection (POI).

Special Operating Requirements

1. DPL 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 DPL.

2. DPL 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 DPL.

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 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

(Results of the steady-state voltage studies should be inserted here)

No issues identified.

Short Circuit

(Summary of impacted circuit breakers)

No issues identified.

Stability and Reactive Power Requirement

No issues identified. See Attachment 2 for full report.

Light Load Analysis – 2020

Light Load Studies to be conducted during later study phases (as required by PJM Manual 14B).

Facilities Study Estimate

X months; $XXX,XXX

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 94.34% to 96.39% (AC power flow) of its emergency rating (1593 MVA) for the single line contingency outage of '220-39'. This project contributes approximately 38.46 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 94.35% to 96.4% (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 38.41 MW to the thermal violation.

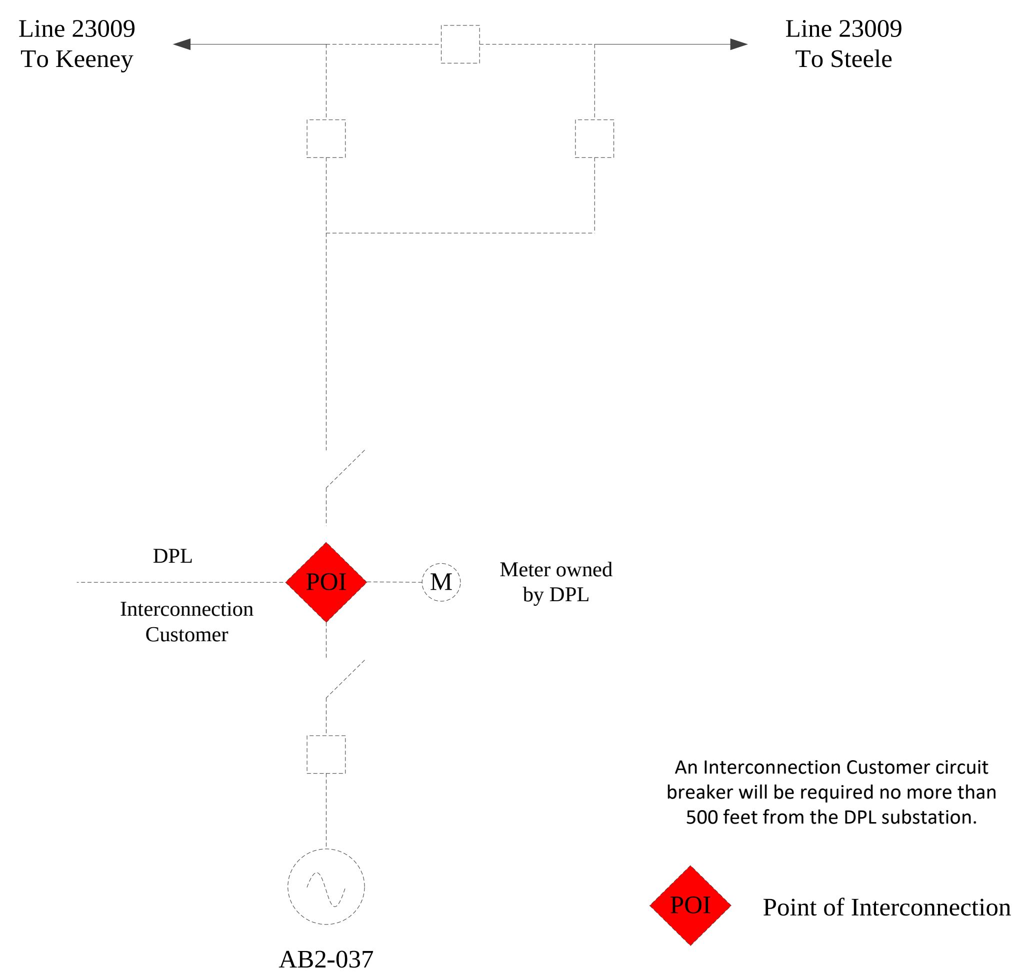
```
CONTINGENCY '220-43/* $ DELCO $ 220-43 $ L'
 TRIP BRANCH FROM BUS 213489 TO BUS 213750 CKT 1          /*
 END/*      $ DELCO $ 220-43 $ L
```

Delmarva Power & Light Costs

Cost estimates will further be refined as a part of the Facilities Study for this project. The Interconnection Customer will be responsible for all costs incurred by DPL in connection with the AB2-037 project. Such costs may include, but are not limited to, any transmission system assets currently in DPL's rate base that are prematurely retired due to the AB2-037 project. PJM shall work with DPL to identify these retirement costs and any additional expenses. DPL reserves the right to reassess issues presented in this document and, upon appropriate justification, submit additional costs related to the AB2-037 project.

Attachment 1

AB2-037
Keeney – Steele 230 kV
New 230 kV Substation



Attachment 2

AB2-037

System Impact Study

Dynamic Simulation Analysis

Prepared by **Michael Yang**

PSC Australia

For **PJM Interconnection, LLC**

Reference **AB2-037-3-0**

Date **February 15, 2017**

Revision Table

Revision	Issue Date	Description
0	February 15, 2017	Initial Release

Reviewers

Name	Interest	Date
Christopher Spencer	Peer Review	February 15, 2017

Approval

Name	Position	Date
Christopher Spencer	Senior Power Systems Engineer	February 15, 2017

TABLE OF CONTENTS

Executive Summary

Generator Interconnection Request AB2-037 is for a 212.5 MW Maximum Facility Output (MFO) solar powered generating facility with a Point of Interconnection (POI) at a tap of the Keeney – Steele 230kV circuit in the Delmarva Power and Light Company (DPL) system, Caroline County, Maryland.

This report describes a dynamic simulation analysis of AB2-037 as part of the overall system impact study.

The load flow scenario for the analysis was based on the RTEP 2020 Summer Peak case, modified to include applicable queue projects. AB2-037 has been dispatched online at maximum power output, with 1.0 pu voltage at the generator bus.

AB2-037 was tested for compliance with NERC, PJM, Transmission Owner and other applicable criteria. 55 contingencies were studied, each with a 10 second simulation time period. Studied faults included:

a) Steady state operation (20 second simulation);
b) Three phase faults with normal clearing time;
c) Single phase faults with stuck breaker;
d) Single phase faults placed at 80% of the line with delayed (Zone 2) clearing at line end remote from fault due to primary communications/relaying failure.
e) Three-phase faults with loss of multi-circuit tower line.

No relevant bus or High Speed Reclosing (HSR) contingencies were found.

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 55 fault contingencies tested on the 2020 Summer Peak case:

a) Post-contingency oscillations were positively damped with a damping margin of at least 3%.
b) The AB2-037 generator was able to ride through all faults (except for faults where protective action trips a generator(s)).
c) Following fault clearing, all bus voltages recovered to a minimum of 0.7 per unit after 2.5 seconds (except where protective action isolates that bus).
d) No transmission element tripped, other than those either directly connected or designed to trip as a consequence of that fault.

A spike in the PELEC output, greater than Pmax, was noted for the AB2-037 generator at fault clearance for contingencies 1B.04 - 1B.12, 1D.01 and 1D.03 - 1D.09.

No mitigations were found to be required.

1. Introduction

Generator Interconnection Request AB2-037 is for a 212.5 MW Maximum Facility Output (MFO) solar powered generating facility with a Point of Interconnection (POI) at a tap of the Keeney-Steele 230kV circuit in the Delmarva Power and Light Company (DPL) system, Caroline County, Maryland.

This analysis is effectively a screening study to determine whether the addition of AB2-037 will meet the dynamic requirements of the NERC, PJM and Transmission Owner reliability standards.

In this report the AB2-037 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

AB2-037 consists of 102 x SMASC 2.08 MW inverters. AB2-037 will be connected to the POI via a 230 / 34.5 kV main collector transformer with a rating of 250 MVA (OA) connected to a 34.5 / 0.385 kV lumped equivalent transformer representing 102 x 2.25 MVA generator step up (GSU) transformers.

The AB2-037 Point of Interconnection (POI) is at a tap of the Keeney – Steele 230kV circuit in the Delmarva Power and Light Company (DPL) system, Caroline County, Maryland as shown in Figure 1.

Table 1 lists the parameters given in the impact study data and the corresponding parameters of the AB2-037 loadflow models.

The dynamic model for the AB2-037 plant is based on the SMA Sunny Central 2200-US PSS/E user defined model supplied by PJM, as indicated by the Developer.

Additional project details are provided in Attachments 1 through 4:

- Attachment 1 contains the Impact Study Data which details the proposed AB2-037 project.
- Attachment 2 shows the one line diagram of the DPL network in the vicinity of AB2-037.
- Attachment 3 provides a diagram of the PSS/E model in the vicinity of AB2-037.
- Attachment 4 gives the AB2-037 PSS/E loadflow and dynamic models of the AB2-037 plant.

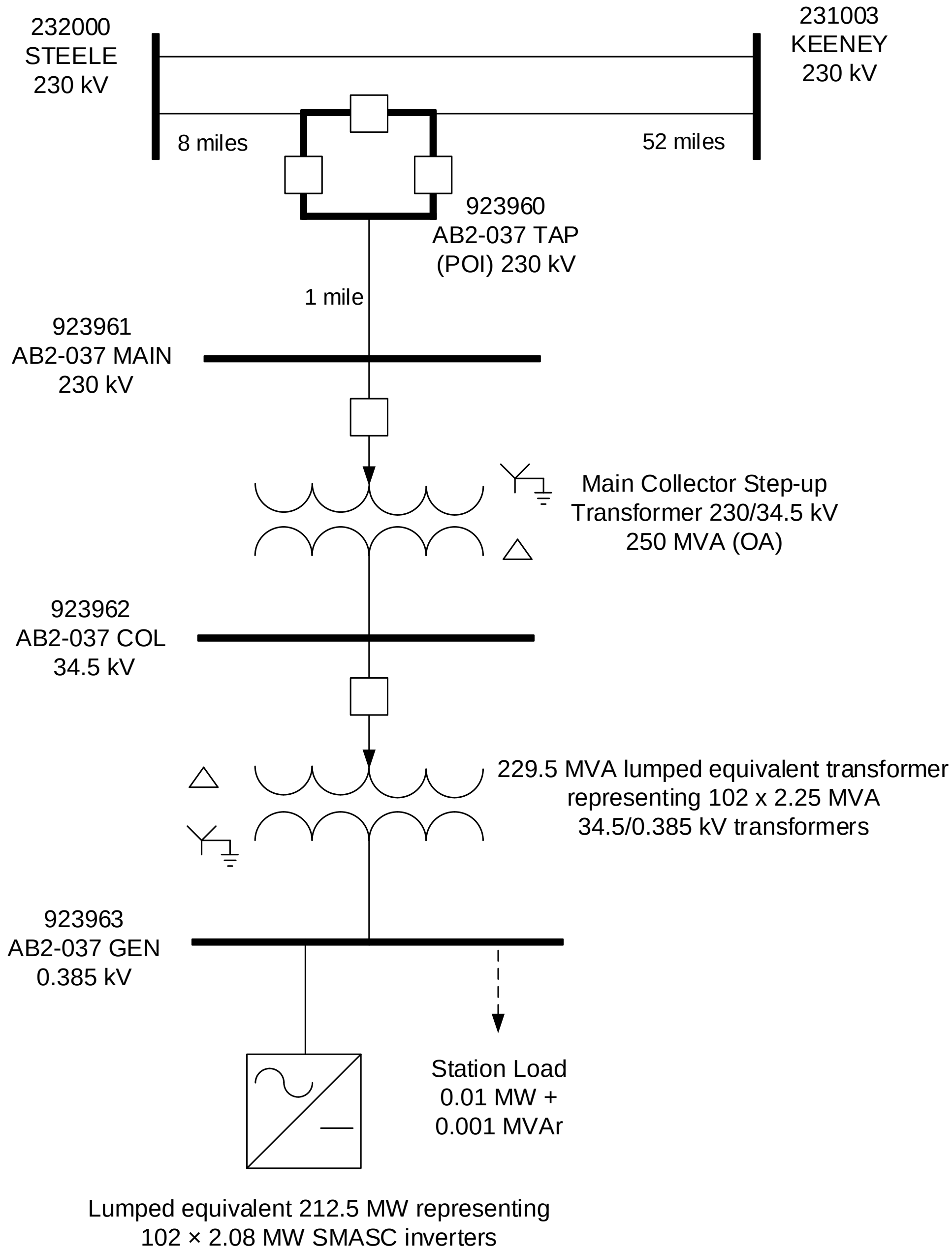


Figure 1: AB2-037 Plant Model

Table 1: AB2-037 Plant Model

	Impact Study Data	Model
Inverter Type	102 × 2.080 MW SMA Sunny Central 2200-US inverters MVA base = 224.4 MVA Vt = 0.385 kV Unsaturated sub-transient reactance = j10000 pu @ MVA base	Lumped equivalent representing 102 × 2.080 MW SMA Sunny Central 2200-US inverters Pgen 212.5 MW Pmax 212.5 MW Pmin 0 MW Qmax 69.8 MVAr Qmin -69.8 MVAr Mbase 224.4 MVA Zsorce j10000 pu @ Mbase
GSU transformer(s)	102 x 34.5/0.385 kV 2.25 MVA two winding transformers Dyn Rating = 2.25 MVA Transformer base = 2.25 MVA (OA) Impedance = 0.01 + j0.0575 pu @ MVA base Number of taps = 5 Tap step size = 2.5%	Lumped equivalent representing 102 x 34.5/0.385 kV 2.25 MVA transformers Transformer base = 229.5 MVA Rating = 229.5 MVA Impedance = 0.01 + j0.0575 pu @ MVA base Number of taps = 5 Tap step size = 2.5%

Main collector step-up transformer	1 x 230/34.5 kV Two winding transformer YNd Rating = 250 MVA (OA/F1/F2) Transformer base = 250 MVA Impedance = 0.0018 + j0.09 pu @ MVA base Number of taps = 5 Tap step size = 2.5%	1 x 230/34.5 kV Two winding transformer Rating = 250 MVA Transformer base = 250 MVA Impedance = 0.0018 + j0.09 pu @ MVA base Number of taps = 5 Tap step size = 2.5%
Station load	0.01 MW + 0.001 MVAr	0.01 MW + 0.001 MVAr (Switched off)
Auxiliary load	N/A	N/A
Transmission line	230 kV 230 MVA Length = 1 mile Impedance = 0.00002 + j0.00014 B = 0.0003	230 kV 230 MVA Length = 1 mile Impedance = 0.00002 + j0.00014 B = 0.0003

3. Loadflow and Dynamics Case Setup

The dynamics simulation analysis was carried out using PSS/E Version 33.7.0.

The load flow scenario and fault cases for this study are based on PJM's Regional Transmission Planning Process[1].

The selected load flow scenario is the RTEP 2020 Summer Peak case with the following modifications:

a) Addition of all applicable queue projects prior to AB2-037.

b) Addition of AB2-037 queue project.

c) Removal of withdrawn and subsequent queue projects in the vicinity of AB2-037.

d) Dispatch of units in the PJM system 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 AB2-037 initial conditions are listed in Table 2, indicating maximum power output, with 1.0 pu voltage at the generator bus.

Table 2: AB2-037 machine initial conditions

Bus	Name	Unit	PGEN	QGEN	ETERM	POI Voltage
923963	AB2-037GEN	1	212.5	-9.38 MVAr	1.000 pu	1.003 pu

Generation within the PJM500 system (area 225 in the PSS/E case) and within the vicinity of AB2-037 has been dispatched online at maximum output (PMAX). The dispatch of generation in the vicinity of AB2-037 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

Tables 3 to 7 list the contingencies that were studied, with representative worst case total clearing times provided by PJM. Each contingency was studied over a 10 second simulation time interval.

The studied contingencies include:

a) Steady state operation (20 second simulation);

b) Three phase faults with normal clearing time;

c) Single phase faults with 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/relaying failure.

e) Three-phase faults with loss of multi-circuit tower line.

No relevant bus or High Speed Reclosing (HSR) contingencies were found.

Buses at which the faults listed above will be applied are

- AB2-037 TAP 230 kV POI
- Steele 230 kV
- Keeney EHV 230 kV

The three phase faults with normal clearing time were performed under network intact conditions.

Additional delayed (Zone 2) clearing at remote and faults will be applied on lines from Harmony 230 kV, Red Lion 230 kV, Milford 230 kV and Vienna 230 kV towards the queue project.

Clearing times listed in Tables 4 to 7 are as per Revision 19 of "*2016 Revised Clearing times for each PJM company"* spreadsheet.

Attachment 2 contains the one-line diagrams of the DPL network in the vicinity of AB2-037, showing where faults were applied.

The positive sequence fault impedances for single line to ground faults were derived from a separate short circuit case, modified to ensure that connected generators in the vicinity of AB2-037 have not withdrawn from the PJM queue, and are not greater than the queue position under study.

5. Evaluation Criteria

This study is focused on AB2-037, along with the rest of the PJM system, maintaining synchronism and having all states return to an acceptable new condition following the disturbance. The recovery criteria applicable to this study are as per PJM's Regional Transmission Planning Process and Transmission Owner criteria:

a) The system with AB2-037 included is transiently stable and post-contingency oscillations should be positively damped with a damping margin of at least 3%.

b) The AB2-037 is able to ride through faults (except for faults where protective action trips AB2-037).

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

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

6. Summary of Results

Plots from the dynamic simulations are provided in Attachment 6, with results summarized in Table 3 through Table 7.

For the 55 fault contingencies tested on the 2020 summer peak case:

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

b) The AB2-037 generator was able to ride through all faults (except for faults where protective action trips a generator(s)).

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

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

A spike in the PELEC output, greater than Pmax, was noted for the AB2-037 generator at fault clearance for contingencies 1B.04 – 1B.12, 1D.01, 1D.03 – 1D.09.

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	AB2-037 No Mitigation
SS.01	Steady state 20 sec	Stable

Table 4: Three-phase Faults With Normal Clearing

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
3N.01	Fault at AB2-037 POI 230 kV on AB2-037 (Trips AB2-037).	7	Stable
3N.02	Fault at AB2-037 POI 230 kV on Keeney EHV circuit 23009.	7	Stable
3N.03	Fault at AB2-037 POI 230 kV on Steele circuit 23009.	7	Stable
3N.04	Fault at Keeney EHV 230 kV on AB2-037 POI circuit 23009.	7	Stable
3N.05	Fault at Keeney EHV 230 kV on Harmony circuit 23010.	7	Stable
3N.06	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 34.5 kV Transformer T2.	7	Stable
3N.07	Fault at Keeney EHV 230 kV on Steele circuit 23001.	7	Stable
3N.08	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 500 kV Transformer AT50.	7	Stable
3N.09	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 500 kV Transformer AT51.	7	Stable
3N.10	Fault at Keeney EHV 230 kV on Harmony circuit 23013.	7	Stable
3N.11	Fault at Keeney EHV 230 kV on Red Lion circuit 23011.	7	Stable
3N.12	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 138 kV Transformer AT20.	7	Stable
3N.13	Fault at Steele 230 kV on AB2-037 POI circuit 23009.	7	Stable
3N.14	Fault at Steele 230 kV on Milford circuit 23076.	7	Stable

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
3N.15	Fault at Steele 230 kV on Vienna circuit 23085.	7	Stable
3N.16	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT21.	7	Stable
3N.17	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT20.	7	Stable
3N.18	Fault at Steele 230 kV on Keeney EHV circuit 23001.	7	Stable
3N.19	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT22.	7	Stable

Table 5: Single-phase Faults With Stuck Breaker

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
1B.01	Fault at AB2-037 POI 230 kV on AB2-037. Breaker to Keeney EHV circuit 23009 stuck. Fault cleared with loss of Keeney EHV circuit 23009 (Trips AB2-037).	7 / 17.5	Stable*
1B.02	Fault at AB2-037 POI 230 kV on Keeney EHV circuit 23009. Breaker to Steele circuit 23009 stuck. Fault cleared with loss of Steele circuit 23009 (Trips AB2-037).	7 / 17.5	Stable*
1B.03	Fault at AB2-037 POI 230 kV on Steele circuit 23009. Breaker to Keeney EHV circuit 23009 stuck. Fault cleared with loss of Keeney EHV circuit 23009 (Trips AB2-037).	7 / 17.5	Stable*
1B.04	Fault at Keeney EHV 230 kV on AB2-037 POI circuit 23009. Breaker 240 stuck. Fault cleared with loss of Harmony circuit 23010.	7 / 17.5	Stable
1B.05	Fault at Keeney EHV 230 kV on Harmony circuit 23010. Breaker 240 stuck. Fault cleared with loss of AB2-037 POI circuit 23009.	7 / 17.5	Stable
1B.06	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 34.5 kV Transformer T2. Breaker 232 stuck. Fault cleared with loss of Red Lion circuit 23011.	7 / 17.5	Stable
1B.07	Fault at Keeney EHV 230 kV on Steele circuit 23001. Breaker 237 stuck. Fault cleared with loss of Keeney EHV 230 / 500 kV Transformer AT50.	7 / 17.5	Stable
1B.08	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 500 kV Transformer AT50. Breaker 237 stuck. Fault cleared with loss of Steele circuit 23001.	7 / 17.5	Stable

* One instance of non-convergence at AB2-037 generator bus was observed during the fault application (at 0.1125s).

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
1B.09	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 500 kV Transformer AT51. Breaker 234 stuck. Fault cleared with loss of Harmony circuit 23013.	7 / 17.5	Stable
1B.10	Fault at Keeney EHV 230 kV on Harmony circuit 23013. Breaker 234 stuck. Fault cleared with loss of Keeney EHV 230 / 500 kV Transformer AT51.	7 / 17.5	Stable
1B.11	Fault at Keeney EHV 230 kV on Red Lion circuit 23011. Breaker 231 stuck. Fault cleared with loss of Keeney EHV 230 / 138 kV Transformer AT20.	7 / 17.5	Stable
1B.12	Fault at Keeney EHV 230 kV on Keeney EHV 230 / 138 kV Transformer AT20. Breaker 231 stuck. Fault cleared with loss of Red Lion circuit 23011.	7 / 17.5	Stable
1B.13	Fault at Steele 230 kV on AB2-037 POI circuit 23009. Breaker 256 stuck. Fault cleared with loss of Steele 230 / 138 kV Transformer AT22.	7 / 17.5	Stable*
1B.14	Fault at Steele 230 kV on AB2-037 POI circuit 23009. Breaker 9240 stuck. Fault cleared with loss of Milford circuit 23076.	7 / 17.5	Stable*
1B.15	Fault at Steele 230 kV on Milford circuit 23076. Breaker 9240 stuck. Fault cleared with loss of AB2-037 POI circuit 23009.	7 / 17.5	Stable*
1B.16	Fault at Steele 230 kV on Milford circuit 23076. Breaker 9230 stuck. Fault cleared with loss of Vienna circuit 23085.	7 / 17.5	Stable*
1B.17	Fault at Steele 230 kV on Vienna circuit 23085. Breaker 9230 stuck. Fault cleared with loss of Milford circuit 23076.	7 / 17.5	Stable*

* One instance of non-convergence at AB2-037 generator bus was observed during the fault application (at 0.1s).

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
1B.18	Fault at Steele 230 kV on Vienna circuit 23085. Breaker 252 stuck. Fault cleared with loss of Steele 230 / 138 kV Transformer AT21.	7 / 17.5	Stable*
1B.19	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT21. Breaker 252 stuck. Fault cleared with loss of Vienna circuit 23085.	7 / 17.5	Stable*
1B.20	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT20. Breaker 9210 stuck. Fault cleared with loss of Keeney EHV circuit 23001.	7 / 17.5	Stable*
1B.21	Fault at Steele 230 kV on Keeney EHV circuit 23001. Breaker 9210 stuck. Fault cleared with loss of Steele 230 / 138 kV Transformer AT20.	7 / 17.5	Stable*
1B.22	Fault at Steele 230 kV on Keeney EHV circuit 23001. Breaker 257 stuck. Fault cleared with loss of Steele 230 / 138 kV Transformer AT22.	7 / 17.5	Stable*
1B.23	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT22. Breaker 257 stuck. Fault cleared with loss of Keeney EHV circuit 23001.	7 / 17.5	Stable*
1B.24	Fault at Steele 230 kV on Steele 230 / 138 kV Transformer AT22. Breaker 256 stuck. Fault cleared with loss of AB2-037 POI circuit 23009.	7 / 17.5	Stable*

Table 6: Single-phase Faults With Delayed (Zone 2) Clearing at line end closest to AB2-037 POI

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
1D.01	Fault at 80% of 230 kV line from AB2-037 POI on Keeney EHV circuit 23009. Delayed clearing at AB2-037 POI 230 kV.	7 / 25	Stable
1D.02	Fault at 80% of 230 kV line from AB2-037 POI on Steele circuit 23009. Delayed clearing at AB2-037 POI 230 kV.	7 / 25	Stable*
1D.03	Fault at 80% of 230 kV line from Keeney EHV on Harmony circuit 23010. Delayed clearing at Keeney EHV 230 kV.	7 / 25	Stable
1D.04	Fault at 80% of 230 kV line from Keeney EHV on Steele circuit 23001. Delayed clearing at Keeney EHV 230 kV.	7 / 25	Stable
1D.05	Fault at 80% of 230 kV line from Keeney EHV on Harmony circuit 23013. Delayed clearing at Keeney EHV 230 kV.	7 / 25	Stable
1D.06	Fault at 80% of 230 kV line from Keeney EHV on Red Lion circuit 23011. Delayed clearing at Keeney EHV 230 kV.	7 / 25	Stable
1D.07	Fault at 80% of 230 kV line from Steele on Milford circuit 23076. Delayed clearing at Steele 230 kV.	7 / 25	Stable
1D.08	Fault at 80% of 230 kV line from Steele on Vienna circuit 23085. Delayed clearing at Steele 230 kV.	7 / 25	Stable
1D.09	Fault at 80% of 230 kV line from Steele on Keeney EHV circuit 23001. Delayed clearing at Steele 230 kV.	7 / 25	Stable

* One instance of non-convergence at AB2-037 generator bus was observed during the fault application (at 0.1s).

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

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	AB2-037 No Mitigation
3T.01	Fault at Keeney EHV 230 kV on Harmony circuit 23010 resulting in tower failure. Fault cleared with loss of Redlion - Hay Road circuit 23020 (Trips Hay Road Generating units HR5, HR6, HR7, HR8 and X1-074). CONTINGENCY 'B47_DPL2	7	Stable
3T.02	Fault at Keeney EHV 230 kV on Red Lion circuit 23011 resulting in tower failure. Fault cleared with loss of Redlion - Hay Road circuit 23020 (Trips Hay Road Generating units HR5, HR6, HR7, HR8 and X1-074). CONTINGENCY 'B47_DPL1	7	Stable

Attachment 1. Impact Study Data

Attachment 2. DPL One Line Diagram

Attachment 3. PSS/E Model One Line Diagram

Attachment 4. AB2-037 PSS/E Dynamic Model

Attachment 5. AB2-037 PSS/E Case Dispatch

Attachment 6. Plots from Dynamic Simulations