Generator Interconnection System Impact Study Report

For

PJM Generation Interconnection Request Queue Position #AB2-093

Ormet 138 kV

May 2017

General

Ohio River Partners Shareholder, LLC (ORP) proposes to install PJM Project #AB2-093, a 485.0 MW (485.0 MW Capacity) 1x1 Single Shaft Combined Cycle Gas Turbine generating facility in Hannibal, OH (see Figure 2). The point of interconnection for the generating facility will be to construct a new nine (9) 138 kV circuit breaker switching station on the existing Ormet 138 kV station site (see Figure 1).

The requested Backfeed date is May 1, 2019.
The requested in-service date is February 15, 2020.

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

Attachment Facilities

Point of Interconnection (Existing Ormet 138 kV Station Site)

To accommodate the interconnection at the existing Ormet 138 kV station site, the existing Ormet 138 kV substation will have to be retired and a new nine (9) circuit breaker 138 kV switching station physically configured in a breaker and half bus arrangement will be constructed (see Figure 1). Installation of associated protection and control equipment, 138 kV line risers, SCADA, and 138 kV revenue metering will also be required. AEP reserves the right to specify the final acceptable configuration considering design practices, future expansion, and compliance requirements.

New Switching Station Work and Cost:

- Construct a new nine (9) circuit breaker 138 kV switching station physically configured in a breaker and half bus arrangement at or near the existing Ormet 138 kV station site. Installation of associated protection and control equipment, 138 kV line risers, SCADA, and 138 kV revenue metering will also be required (see Figure 1).
- **Estimated New 138 kV Station Cost: $13,000,000**
- **Estimated Retirement Cost of the Existing Ormet 138 kV Station: $2,000,000**
- **Estimated 138 kV Revenue Metering Cost: $150,000**

Protection and Relay Work and Cost:

- Install line protection and controls at the new 138 kV switching station.
- **Estimated Cost: $2,000,000**

- **Upgrade line protection and controls at the Kammer 138 kV substation to coordinate with the new 138 kV switching station.**
- **Estimated Cost: $500,000**

Note: Since ORP has indicated their preference to locate the new switching station on the existing Ormet grounds, an environmental assessment will need to be conducted and all environment issues identified in the assessment will have to be addressed prior to start of construction on the site. In addition, for AEP to undertake ownership and operation of the Interconnection station, ownership of the existing non-AEP-owned portion of the transmission lines terminating at the existing station will need to be transferred to AEP. Alternatively, some other entity owning these portions of the transmission lines would have to assume responsibility for meeting the Transmission Owner requirements for NERC Compliance and PJM Transmission-Owning Member purposes. Station access will also be required. Also, provisions will have to be made to serve the other existing AEP customer load during construction of the new station.

It is understood that ORP is responsible for all costs associated with this interconnection. The cost of ORP's generating plant and the costs for the line connecting the generating plant to ORP's switching station are not included in this report; these are assumed to be ORP's responsibility.

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

Local and Network Impacts

The impact of the proposed generating facility on the AEP System was assessed for adherence with applicable reliability criteria. AEP planning criteria require that the transmission system meet performance parameters prescribed in the AEP FERC Form 715[1] and Connection Requirements for AEP Transmission System[2]. Therefore, these criteria were used to assess the impact of the proposed facility on the AEP System. The Queue Project AB2-093 was evaluated as a 485.0 MW (Capacity 485.0 MW) injection into the Ormet 138 kV substation in the AEP area. Project AB2-093 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AB2-093 was studied with a commercial probability of 100%. Potential network impacts were as follows:

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[1] https://www.aep.com/about/codeofconduct/OASIS/TransmissionStudies/docs/2017/AEP_East%20FERC%20715_2017_Final_Part%204.pdf

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

Summer Peak Analysis - 2020

Generator Deliverability

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

Table 1 - Generator Deliverability

#	Contingency Type	Contingency Name	Affected Area	Facility Description	Bus From	Bus To	Cir.	PF	Loading Initial	Loading Final	Rating Type	Rating MVA	MW Con.	FG App.
1	Non	Non	AEP - AEP	KAMMER-WASHINGTON 138 kV line	243026	243012	1	AC	79.7	100.9	NR	389	85.3	

Limiting Elements

- The 0.08 miles of the ACSR 1590 54/19 FALCON conductor section 2

Multiple Facility Contingency

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

Table 2 - Multiple Facility Contingency

#	Contingency Type	Contingency Name	Affected Area	Facility Description	Bus From	Bus To	Cir.	PF	Loading Initial	Loading Final	Rating Type	Rating MVA	MW Con.	FG App.
2	DCTL	476	AEP - AEP	KAMMER-WASHINGTON 138 kV line	243026	243012	1	AC	90.2	106.5	ER	550	92	1

Limiting Elements

- The 0.08 miles of the ACSR 1590 54/19 FALCON conductor section 2
- The George Washington Wavetrap (2000A)
- The Kammer Wavetrap (2000A)

Contribution to Previously Identified Overloads

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

None

Short Circuit

(Summary of impacted circuit breakers)

None

Stability Analysis

No problems identified – See Attached Stability report in Attachment 1

Voltage Variations

None

Delivery of Energy Portion of Interconnection Request

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

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

Not Applicable

Additional Limitations of Concern

None

Light Load Analysis

Not required

New System Reinforcements

1. To relieve the Kammer – George Washington 138 kV line overloads:

    - Reconductor 0.08 miles of the ACSR 1590 (54/19) Falcon conductor section 2
    - Estimated Cost: $100,000
    - Replace the George Washington wavetrap (2000 A)
    - Estimated Cost: $100,000
    - Replace the Kammer wavetrap (2000 A)
    - Estimated Cost: $100,000

Total Cost of Upgrades: $300,000
PJM Network Upgrade N5304

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)

AB2-093 does not receive cost allocation towards the Y3-068 network upgrades for the George Washington GIS substation. These network upgrades and costs were needed to relieve 69 kV system violations caused by Y3-068. However, AB2-093 may need the following network and baseline upgrades in-service in order to be deliverable to the PJM and AEP systems as these upgrades were modeled in the AB2-093 Impact Study 2020 case:

Baseline Upgrades B2753.1 – B2753.10

Network Upgrades N5076.1 – N5076.8

Baseline Upgrade B2605

If AB2-093 comes into service prior to any of these upgrades or summer 2020, an interim study may be required for AB2-093.

Schedule

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

Additional Interconnection Customer Responsibilities:

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

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

Conclusion

Based upon the results of this System Impact Study, the construction of the 485.0 MW (485.0 MW Capacity) natural gas generating facility of ORP (PJM Project #AB2-093) will require the following additional interconnection charges. This plan of service will interconnect the proposed generating facility in a manner that will provide operational reliability and flexibility to both the AEP system and the ORP natural gas generating facility.

Cost Breakdown for Point of Interconnection (Existing Ormet 138 kV Site)			**Network Upgrade Number**
Attachment Cost	New 138 kV Switching Station on Existing Ormet Site	**$13,000,000**	**n5327**
Non-Direct Connection Cost Estimate	Install line protection and controls at the new 138 kV switching station.	**$2,000,000**	**n5328**
	138 kV Revenue Metering	**$150,000**	**n5329**
	Retire Existing Ormet 138 kV Substation	**$2,000,000**	**n5330**
	Upgrade line protection and controls at the Kammer 138 kV substation to coordinate with the new 138 kV switching station.	**$500,000**	**n5331**
	The following upgrades are required to relieve the Kammer – George Washington 138 kV line overloads:		**n5304**
	▪ Reconductor 0.08 miles of the ACSR 1590 (54/19) Falcon conductor section 2	**$100,000**	
	▪ Replace the George Washington wavetrap (2000 A)	**$100,000**	
	▪ Replace the Kammer wavetrap (2000 A)	**$100,000**	
Total Estimated Cost for Project AB2-093		**$17,950,000**	

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

Figure 1: Point of Interconnection (Existing Ormet 138 kV Site)
Single-Line Diagram

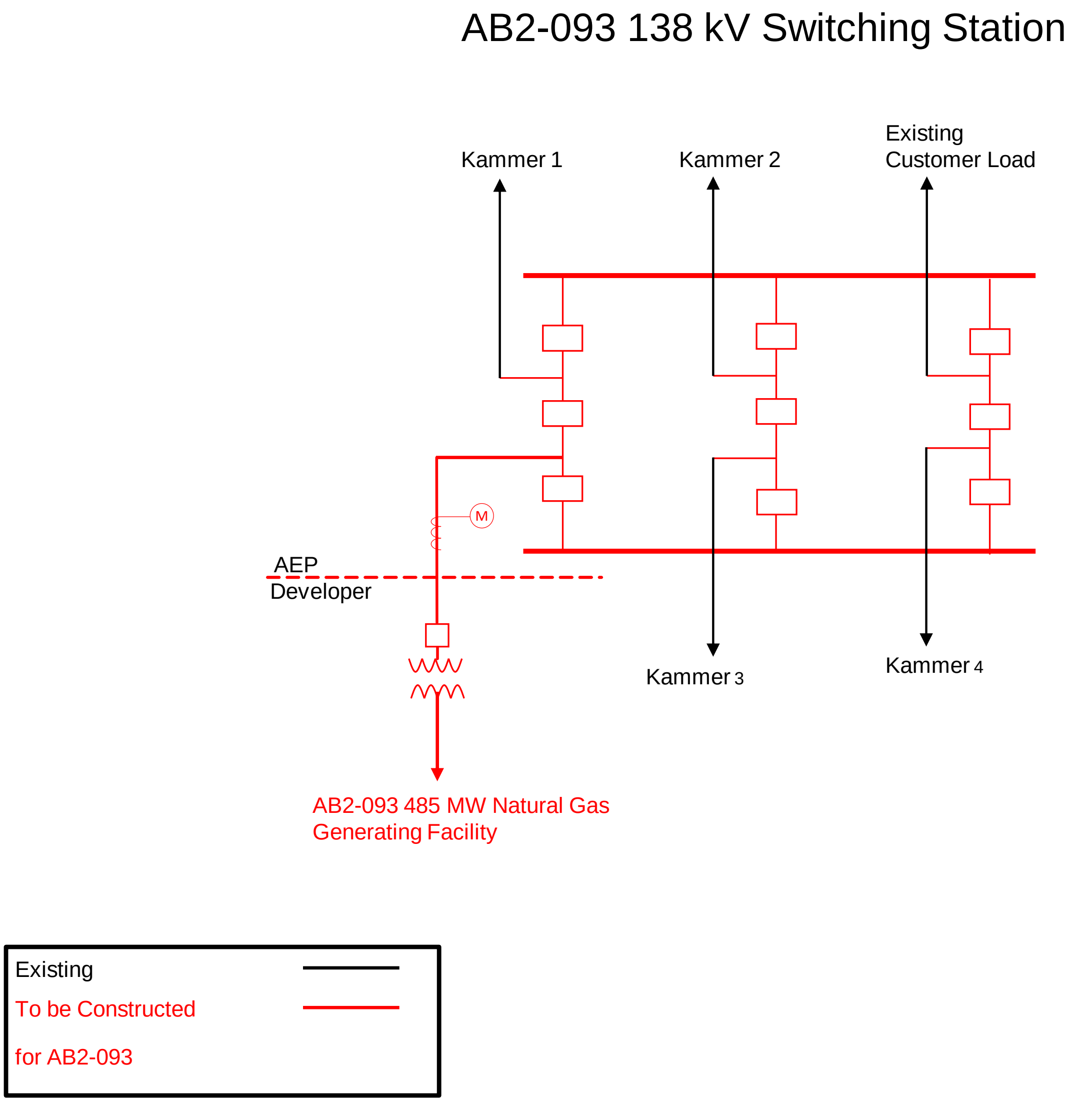
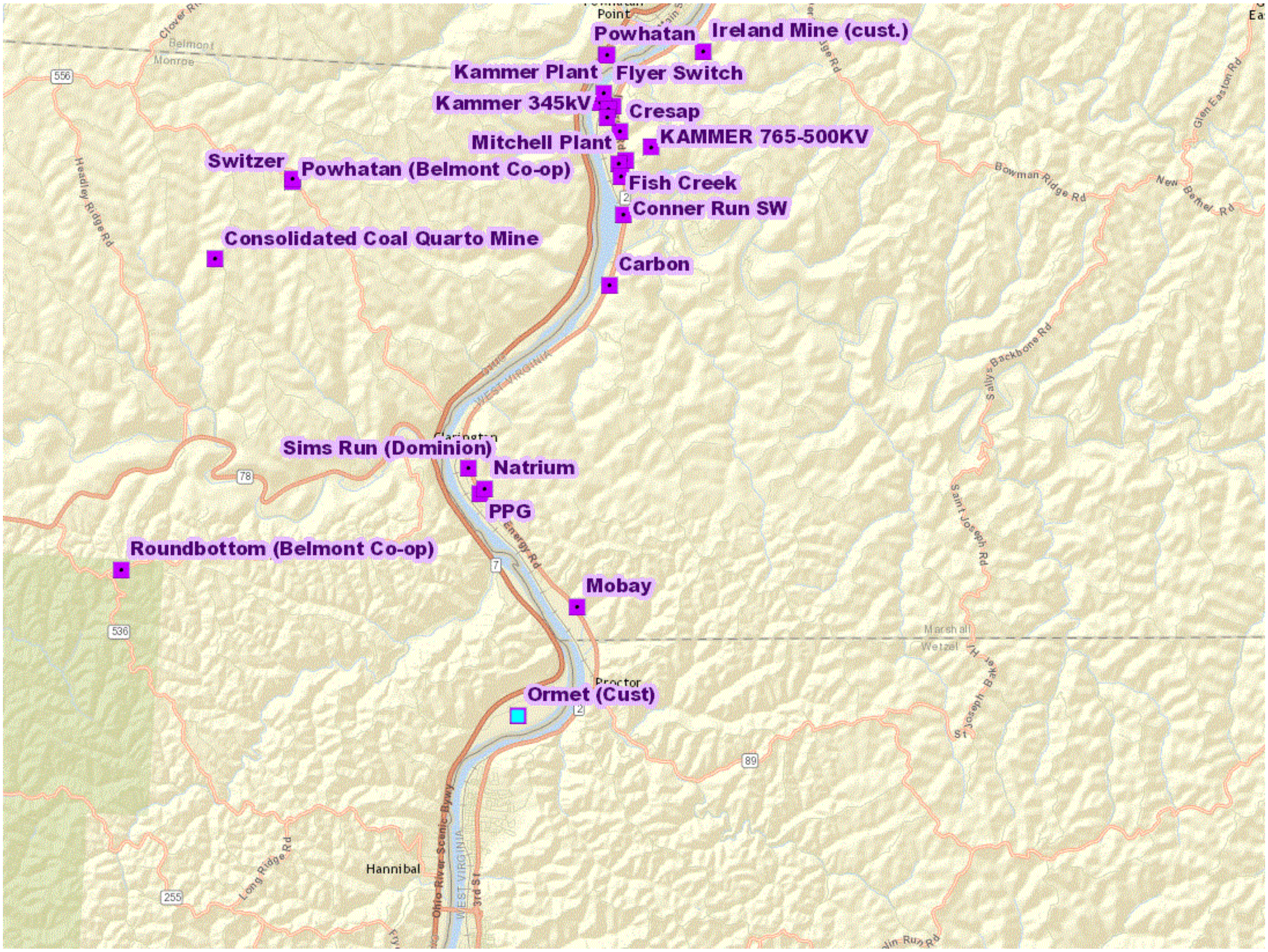


Figure 2: Point of Interconnection (Existing Ormet 138 kV Site)



Appendices

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

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

Appendix 1

(AEP - AEP) The 05KAMMR1-05G WASH 138 kV line (from bus 243026 to bus 243012 ckt 1) loads from 90.21% to 106.52% (AC power flow) of its emergency rating (550 MVA) for the tower line contingency outage of '476'. This project contributes approximately 91.96 MW to the thermal violation.

CONTINGENCY '476'
OPEN BRANCH FROM BUS 242931 TO BUS 247130 CKT 1 / 242931 05BEVERL 345 247130 05HOLLOW 345 1
OPEN BRANCH FROM BUS 242937 TO BUS 242948 CKT 1 / 242937 05KAMMER 345 242948 05WBELLA 345 1
END

Bus Number	*Bus Name*	*Full Contribution*
243189	*05MLG2*	*20.75*
244996	*05ROSEVALL*	*-0.06*
923312	*AB1-140*	*-4.3*
924441	*AB2-093*	*91.96*

Attachment 1 – Stability Analysis

Executive Summary

Generator Interconnection Request AB2-093 is for a 485 MW Maximum Facility Output (MFO) Single Shaft Combined Cycle Gas Turbine (CT). AB2-093 consists of 1x 497 MW CT with a Point of Interconnection (POI) at the Ormet 138 kV station in the American Electric Power (AEP), Monroe County, Ohio.

This report describes a dynamic simulation analysis of AB2-093 as part of the overall system impact study.

The load flow scenario for the analysis was based on the RTEP 2020 light load case, modified to include applicable queue projects. AB2-093 has been dispatched online at maximum power output, with 0.95 p.u. voltage at the generator bus.

AB2-093 was tested for compliance with NERC, PJM, Transmission Owner and other applicable criteria. 45 contingencies were studied, each with a 20 second simulation time period. Studied faults included:

a) Steady state operation;

b) Three phase faults with normal clearing time;

c) Three phase faults with unsuccessful high speed reclosing.

d) Single phase faults with stuck breaker;

e) 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;

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

No relevant single phase bus fault 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 all 45 of the fault contingencies tested on the 2020 light load case:

a) AB2-093 was able to ride through the faults (except for faults where protective action trips a generator(s)),

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

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.

No mitigations were found to be required.

1. Introduction

Generator Interconnection Request AB2-093 is for a 485 MW Maximum Facility Output (MFO) Single Shaft Combined Cycle Gas Turbine (CT). AB2-093 consists of 1 x 497 MW CT with a Point of Interconnection (POI) at the Ormet 138 kV Substation in the American Electric Power (AEP), Monroe County, Ohio.

This analysis is effectively a screening study to determine whether the addition of AB2-093 will meet the dynamic requirements of the NERC, PJM and Transmission Owner reliability standards.

In this report the AB2-093 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

AB2-093 consists of 1 x 497 MW combustion turbine. AB2-093 will be connected to the POI via a 373 MVA 345/24 kV GSU transformer. AB2-093 connects at the Ormet 138 kV Substation, as shown in Figure 1.

Table 1 lists the parameters given in the impact study data and the corresponding parameters of the AB2-093 load flow model.

Additional project details are provided in Attachments 1 through 4:

- Attachment 1 contains the Impact Study Data which details the proposed AB2-093 project.
- Attachment 2 shows the one-line diagrams of the First Energy (FE) and AEP networks in the vicinity of AB2-093.
- Attachment 3 provides a diagram of the PSS/E model in the vicinity of AB2-093.
- Attachment 4 gives the PSS/E load flow and dynamic models of AB2-093.

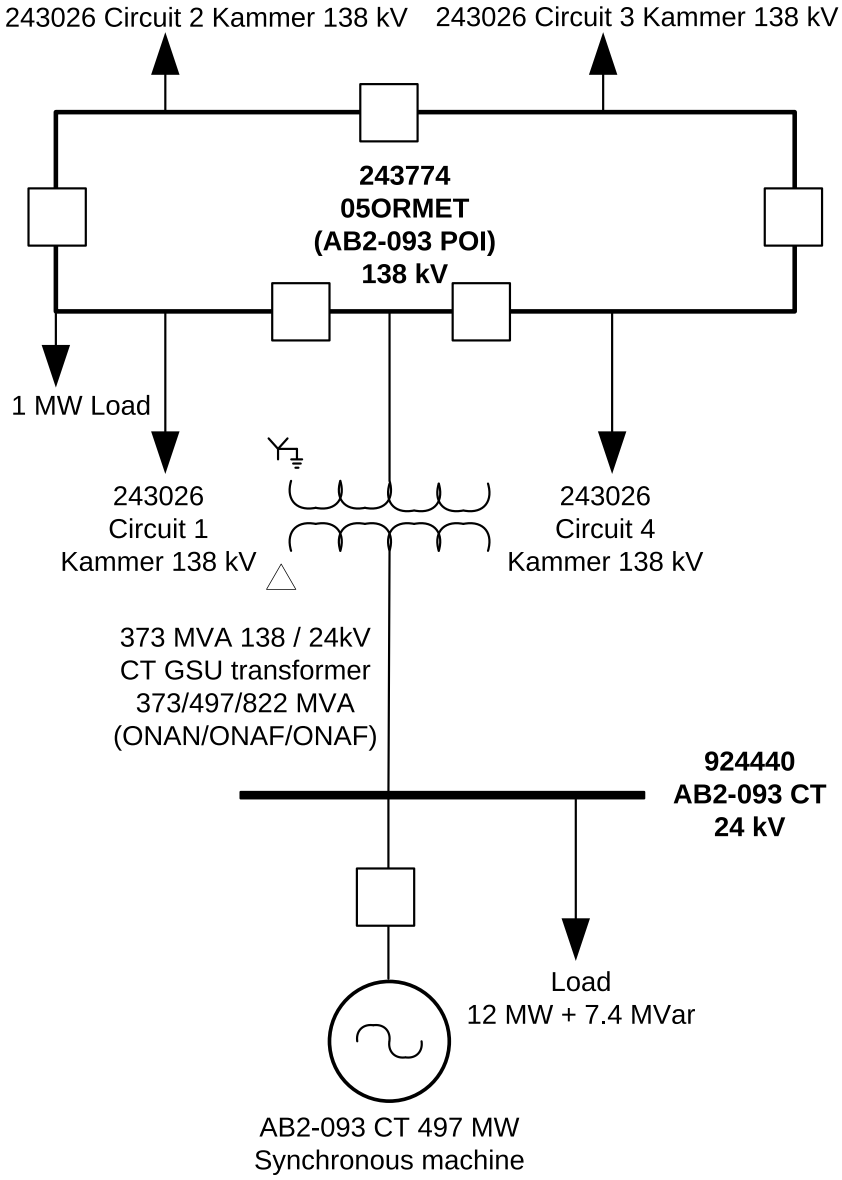


Figure 1: AB2-093 Plant Model[3]

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[3] Breaker diagram for POI was not confirmed at the time of study. An assumed breaker configuration is shown in Figure 1.

Table 1: AB2-093 Plant Model

	Impact Study Data	Model
Turbine Type	1 x 497 MW Single Shaft Combined Cycle Gas Turbine MVA base = 706 MVA Vt = 24 kV Unsaturated sub-transient reactance = 0.245 pu @ MVA base	1 x 497 MW generator Pgen 497 MW Pmax 497 MW Pmin 0 MW Qgen -141.63 MVAr Qmax[4] 308 MVAr Qmin[2] -163 MVAr Mbase 706 MVA Zsorce j0.245 pu @ Mbase
GSU transformer	1 x 138 kV / 24 kV Transformer Rating = 373/497/822 MVA (ONAN/ONAF/ONAF) Transformer base = 373 MVA Impedance = 0.005987 + j0.0898 pu @ MVA base Number of taps = N/A Tap step size = N/A	1 x 138 kV / 24 kV Transformer Rating = 373/497/822 MVA Transformer base = 373 MVA Impedance = 0.005987 + j0.0898 pu @ MVA base Number of taps = 5 Tap step size = 2.5%
Auxiliary load	11 MW + 6.8 MVAr	12 MW + 7.4 MVAr on Low Voltage side of the GSU
Station load	1 MW + 0.6 MVAr	
Transmission line	N/A	N/A

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[4] The Leading and lagging values are from Impact Study Datasheet as it represented the most conservative data.

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[5].
The selected load flow scenario is the RTEP 2020 light load case with the following modifications:

a) Addition of all applicable queue projects prior to AB2-093.

b) Addition of AB2-093 queue project.

c) Removal of withdrawn and subsequent queue projects in the vicinity of AB2-093.

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 AB2-093 initial conditions are listed in Table 3, indicating maximum power output, with leading power factor.

Table 2: AB2-093 machine initial conditions

Bus	Name	Unit	PGEN	QGEN	ETERM	POI Voltage
924440	AB2-093 CT	1	497.0 MW	-141.634 MVAr	0.95 pu	0.9876 pu

Generation within the PJM500 system (area 225 in the PSS/E case) and within the vicinity of AB2-093 has been dispatched online at maximum output (PMAX). The dispatch of generation in the vicinity of AB2-093 is given in Attachment 5.

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[5] 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 8 list the contingencies that were studied, with representative worst case total clearing times provided by PJM. Each contingency was studied over a 20 second simulation time interval.

The studied contingencies include:

a) Steady state operation;

b) Three phase faults with normal clearing time;

c) Three phase faults with unsuccessful high speed reclosing;

d) Single phase faults with stuck breaker;

e) 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;

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

High speed reclosing (HSR) contingencies were identified with less than 1 s reclosing time in the first attempt. Only unscuccessful high speed reclosing into a fault was considered.

No relevant single phase bus fault contingencies were identified.

The contingencies listed above were applied to:

- Ormet POI 138 kV
- Kammer South Station 138 kV
- Kammer North Station 138 kV

The three phase faults with normal clearing time were performed under network intact conditions and with prior outage of:

- Kammer 345/138 kV transformer 302

Three phase faults with unsuccessful high speed reclosing were considered on circuits from Kammer South and Kammer North 138 kV Substations.

Kammer 138/345 kV Transformer 300 should be retired in the models and 301 should be normally open (baseline upgrade b2753.9) as confirmed by the TO.

Clearing times listed in Tables 3 to 8 are as per Revision 19 of "*2016 Revised Clearing times for each PJM company"* spreadsheet.

Attachment 2 contains the one-line diagrams of the FE and AEP networks in the vicinity of AB2-093, showing where faults were applied.

The positive sequence fault impedances for single line to ground faults were derived from the stability case directly by using the ASCC fault calculation method and zero/positive sequence impedance ratio provided by PJM.

5. Evaluation Criteria

This study is focused on AB2-093, 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) AB2-093 is able to ride through the faults (except for faults where protective action trips a generator(s)),

b) The system with AB2-093 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.

6. Summary of Results

Plots from the dynamic simulations are provided in Attachment 6, with results summarized in Table 3 through Table 8.

For all 45 of the fault contingencies tested on the 2020 light load case:

a) AB2-093 was able to ride through the faults (except for faults where protective action trips a generator(s)),

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

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.

No mitigations were found to be required.

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 20 sec	Stable

Table 4: Three-phase Faults with Normal Clearing / Unsuccessful High Speed Reclosing

Fault ID	Fault description	Clearing/HSR Times (Cycles)	Result No Mitigation
3N.01	Fault at Ormet (AB2-093 POI) 138 kV on AB2-093 circuit (Trips AB2-093).	5.5 / NA	Stable
3N.02	Fault at Ormet (AB2-093 POI) 138 kV on Kammer South circuit 1 (Trips Ormet load).	5.5 / NA	Stable
3N.03	Fault at Kammer South Station 138 kV on Ormet No. 1 circuit. • Fault cleared after 5.5 cycles with loss of Ormet No. 1 circuit and Ormet load. • High speed reclosers I2 and I close after 15 cycles (20.5 cycles total) reconnecting Ormet No. 1 circuit and Ormet load. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening Ormet No. 2 circuit.	5.5 / 15	Stable
3N.04	Fault at Kammer South Station 138 kV on FGD circuit 1 (Trips FGD load).	5.5 / NA	Stable
3N.05	Fault at Kammer South Station 138 kV on Kammer 138/345 kV Transformer 303.	5.5 / NA	Stable
3N.06	Fault at Kammer South Station 138 kV on West Bellaire circuit. • Fault cleared after 5.5 cycles with loss of West Bellaire circuit. • High speed reclosers F and F1 close after 15 cycles (20.5 cycles total) reconnecting West Bellaire circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening West Bellaire circuit.	5.5 / 15	Stable
3N.07	Fault at Kammer North Station 138 kV on George Washington circuit. • Fault cleared after 5.5 cycles with loss of George Washington circuit. • High speed reclosers C and C2 close after 15 cycles (20.5 cycles total) reconnecting George Washington circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening George Washington circuit	5.5 / 15	Stable
3N.08	Fault at Kammer North Station 138 kV on Natrium circuit. • Fault cleared after 5.5 cycles with loss of Natrium circuit. • High speed reclosers E and E2 close after 15 cycles (20.5 cycles total) reconnecting Natrium circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening Natrium circuit.	5.5 / 15	Stable

Fault ID	**Fault description**	**Clearing/HSR Times (Cycles)**	**Result No Mitigation**
3N.09	Fault at Kammer North Station 138 kV on Big Grave Creek – Aston circuit. • Fault cleared after 5.5 cycles with loss of Big Grave Creek – Aston circuit. • High speed reclosers D and D2 close after 15 cycles (20.5 cycles total) reconnecting Big Grave Creek – Aston circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening Big Grave Creek – Aston circuit.	5.5 / 15	Stable
3N.10	Fault at Kammer North Station 138 kV on Kammer 138/345 kV Transformer 302.	5.5 / NA	Stable
3N.11	Fault at Kammer North Station 138 kV on Kammer 138/69 kV Transformer.	5.5 / NA	Stable

Table 5: Single-phase Faults with Stuck Breaker, Single Phase Delayed Clearing

Fault ID	Fault description	Clearing Time Normal & Delayed (Cycles)	Result No Mitigation
1B.01	Fault at Ormet (AB2-093 POI) 138 kV on AB2-093 circuit (Trips AB2-093). Breaker stuck to Kammer circuit 1. Fault cleared with loss of Kammer circuit 1 and Ormet load.	5.5 / 16	Stable
1B.02	Fault at Ormet (AB2-093 POI) 138 kV on Kammer South circuit 1. Breaker stuck to AB2-093 circuit. Fault cleared with loss of AB2-093 circuit (Trips AB2-093) and Ormet load.	5.5 / 16	Stable
1B.03	Fault at Ormet (AB2-093 POI) 138 kV on Kammer South circuit 1. Breaker stuck to Kammer South circuit 2. Fault cleared with loss of Kammer South circuit 2 and Ormet load.	5.5 / 16	Stable
1B.04	Fault at Kammer South Station 138 kV on Ormet No. 4 circuit. Breaker F stuck. Fault cleared with loss of West Bellaire circuit.	5.5 / 16	Stable
1B.05	Fault at Kammer South Station 138 kV on Ormet No. 3 circuit. Breaker G stuck. Fault cleared with loss of Kammer 345/138 kV Transformer 303.	5.5 / 16	Stable
1B.06	Fault at Kammer South Station 138 kV on Ormet No. 2 circuit. Breaker H stuck. Fault cleared without loss of additional circuits.	5.5 / 16	Stable
1B.07	Fault at Kammer South Station 138 kV on Ormet No. 1 circuit. Breaker I stuck. Fault cleared with loss of FGD circuit 1, FGD load and Ormet load.	5.5 / 16	Stable
1B.08	Fault at Kammer South Station 138 kV on Ormet No. 1 circuit. Breaker I2 stuck. Fault cleared with loss of Kammer South bus section 4 (Trips Kammer 43.2 MVAr Capacitor bank) and Ormet load.	5.5 / 16	Stable
1B.09	Fault at Kammer South Station 138 kV on FGD circuit 1. Breaker I stuck. Fault cleared with loss of Ormet No. 1 circuit, Ormet load and FGD load.	5.5 / 16	Stable
1B.10	Fault at Kammer South Station 138 kV on FGD circuit 2. Breaker J2 stuck. Fault cleared with loss of Kammer South Bus 4 (Trips Kammer Cap bank 43.2 MVAr) and FGD load.	5.5 / 16	Stable
1B.11	Fault at Kammer South Station 138 kV on Kammer 138/345 kV Transformer 303. Breaker G stuck. Fault cleared with loss of Ormet No. 3 circuit.	5.5 / 16	Stable
1B.12	Fault at Kammer South Station 138 kV on West Bellaire circuit. Breaker F stuck. Fault cleared with loss of Ormet No. 4 circuit.	5.5 / 16	Stable
1B.13	Fault at Kammer North Station 138 kV on George Washington circuit. Breaker C2 stuck. Fault cleared without loss of additional circuits.	5.5 / 16	Stable
1B.14	Fault at Kammer North Station 138 kV on Kammer 345/138 kV Transformer 302. Breaker D stuck. Fault cleared with loss of Big Grave Creek – Aston circuit.	5.5 / 16	Stable
1B.15	Fault at Kammer North Station 138 kV on Natrium circuit. Breaker E stuck. Fault cleared without loss of additional circuits.	5.5 / 16	Stable

Fault ID	Fault description	Clearing Time Normal & Delayed (Cycles)	Result No Mitigation
1B.16	Fault at Kammer North Station 138 kV on Big Grave Creek – Aston circuit. Breaker D stuck. Fault cleared with loss of Kammer 345/138 kV Transformer 302.	5.5 / 16	Stable
1B.17	Fault at Kammer North Station 138 kV on Big Grave Creek – Aston circuit. Breaker D2 stuck. Fault cleared without loss of additional circuits.	5.5 / 16	Stable
1B.18	Fault at Kammer North Station 138 kV on Kammer 138/69 kV Transformer. Breaker B2 stuck. Fault cleared with no loss of additional circuits.	5.5 / 16	Stable

Table 6: Single-phase Faults with Delayed Clearing (Zone 2) at Line Closest to AB2-093 POI

Fault ID	Fault description	Clearing Time Normal and Delayed (Cycles)	Result No Mitigation
1D.01	Fault at 80% of line from Ormet (AB2-093 POI) 138 kV on Kammer South circuit 1. Delayed clearing at Ormet (AB2-093 POI) 138 kV. Fault cleared with the loss of Ormet load.	5.5 / 60	Stable
1D.02	Fault at 80% of line from Kammer South Station 138 kV on FGD circuit 1. Delayed clearing at Kammer. Fault cleared with loss of FGD load.	5.5 / 60	Stable
1D.03	Fault at 80% of line from Kammer South Station 138 kV on West Bellaire circuit. Delayed clearing at Kammer.	5.5 / 60	Stable
1D.04	Fault at 80% of line from Kammer North Station 138 kV on George Washington circuit. Delayed clearing at Kammer.	5.5 / 60	Stable
1D.05	Fault at 80% of line from Kammer North Station 138 kV on Natrium circuit. Delayed clearing at Kammer.	5.5 / 60	Stable
1D.06	Fault at 80% of line from Kammer North Station 138 kV on Big Grave Creek – Aston circuit. Delayed clearing at Kammer.	5.5 / 60	Stable

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

Fault ID	Fault description	Clearing Time (Cycles)	Result No Mitigation
1T.01	Fault at Ormet (AB2-093 POI) 138 kV on Kammer South circuit 1 (Trips Ormet load). Fault cleared with additional loss of: • Ormet (AB2-093 POI) – Kammer South 138 kV circuit 2.	5.5	Stable
1T.02	Fault at Ormet (AB2-093 POI) 138 kV on Kammer South circuit 3. Fault cleared with additional loss of: • Ormet (AB2-093 POI) – Kammer South 138 kV circuit 4.	5.5	Stable
1T.03	Fault at Kammer North 138 kV on Big Grave Creek – Aston circuit resulting in tower failure. Fault cleared with additional loss of: • George Washington – Big Grave Creek Tap /Big Grave Creek – Valley Grove – Battle Run Switch – West Liberty – Tidd 138 kV circuit. CONTINGENCY '7434'	5.5	Stable

Fault ID	**Fault description**	**Clearing Time (Cycles)**	**Result No Mitigation**
1T.04	Fault at Kammer North 138 kV on Big Grave Creek – Aston circuit resulting in tower failure. Fault cleared with additional loss of: • George Washington – Natrium 138 kV circuit. CONTINGENCY '9035'	5.5	Stable
1T.05	Fault at Kammer 138 kV on Natrium circuit resulting in tower failure. Fault cleared with additional loss of: • Natrium – George Washington 138 kV circuit. CONTINGENCY '9036'	5.5	Stable

Table 8: Three-phase Faults with Normal Clearing – Prior outage of Kammer 345/138 kV Transformer 302

Fault ID	Fault description	Clearing/HSR Times (Cycles)	Result No Mitigation
MA.3N.06	Fault at Kammer South Station 138 kV on West Bellaire circuit. • Fault cleared after 5.5 cycles with loss of West Bellaire circuit. • High speed reclosers F and F1 close after 15 cycles (20.5 cycles total) reconnecting West Bellaire circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening West Bellaire circuit.	5.5 / 15	Stable
MA.3N.07	Fault at Kammer North Station 138 kV on George Washington circuit. • Fault cleared after 5.5 cycles with loss of George Washington circuit. • High speed reclosers C and C2 close after 15 cycles (20.5 cycles total) reconnecting George Washington circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening George Washington circuit	5.5 / 15	Stable
MA.3N.08	Fault at Kammer North Station 138 kV on Natrium circuit. • Fault cleared after 5.5 cycles with loss of Natrium circuit. • High speed reclosers E and E2 close after 15 cycles (20.5 cycles total) reconnecting Natrium circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening Natrium circuit.	5.5 / 15	Stable
MA.3N.09	Fault at Kammer North Station 138 kV on Big Grave Creek – Aston circuit. • Fault cleared after 5.5 cycles with loss of Big Grave Creek – Aston circuit. • High speed reclosers D and D2 close after 15 cycles (20.5 cycles total) reconnecting Big Grave Creek – Aston circuit. • Reclose unsuccessful, fault cleared after 5.5 cycles (26 cycles total) by opening Big Grave Creek – Aston circuit.	5.5 / 15	Stable