PJM Generator Interconnection Request
Queue #X4-025
Millbrook Park (South Shore) 138kV
Impact Study

757093
June 2013

X4-025 Millbrook Park (South Shore) 138kV Impact Study

General

Sun Coke Energy (Sun Coke) proposes to install PJM Project #X4-025, an 80 MW (net) generating facility comprised of 1-90 MW (gross) steam turbine generator connecting to the American Electric Power (AEP) Millbrook Park station via a customer owned 138 kV transmission line. Sun Coke is building a multi-oven (over 100) coke facility and will use the waste heat to power the steam turbine. The proposed project will be located on US Route 23 between Johnson Lane and KY Route 2538, two miles East of South Shore, Greenup County, Kentucky. See Exhibit #1. The requested in-service date is November 1, 2014.

The intent of the Impact study is to determine system reinforcements and associated costs and construction time estimates required to facilitate the addition of the new generating plant to the transmission system. The reinforcements include the direct connection of the generator to the system and any network upgrades necessary to maintain the reliability of the transmission system.

Depending on the final configuration, AEP-Kentucky Power may require Sun Coke to submit a request for and take retail service from AEP-Kentucky Power, which will utilize the interconnection metering for the settlement of real and reactive power delivered to the generating facility during times of net consumption. Retail service settlements for the generating facility are not required during hours of net generation. If the final configuration treats the generating facilities as behind the meter, the aforementioned retail service will not be required, and the generating facility consumption will be treated as Sun Coke industrial load.

Attachment Facilities

X4-025 was originally studied as 130 MW at the Feasibility stage assuming U2-080 was in service since the customer-owned line and attachment facilities from U2-080 would have been used to serve X4-025. Sun Coke has since cancelled queue project U2-080 and requested that X4-025 be reduced to 80 MW. As a result, the X4-025 Impact Study will assume the same attachment facilities and customer owned line that would have been built under U2-080 will now be built under X4-025.

X4-025 now proposes to connect directly to Millbrook Park station via a new customer owned/constructed radial 138 kV line. AEP's ownership of the 138 kV system facilities will end at (and not include) the first structure outside of the Millbrook Park station fence.

Millbrook Park station will require new 138 kV circuit breaker(s), control relay(s), a SCADA RTU, and a metering package. It will also be necessary for AEP to install up to two structures inside the Millbrook Park station fence to extend the customer line into the proper termination point. The customer owned/constructed 138 kV line is required to include fiber optic communication cable either in the form of OPGW or ADSS. The customer must work with AEP Protection & Control when deciding on its own relaying devices to make sure they can properly work together with AEP's relaying.

Due to the compliance issues associated with Bulk Electric System (BES) facilities, AEP is required to periodically take BES 138 kV breakers out of service for regular maintenance. These requirements are applicable to the proposed breaker(s) at Millbrook Park that would serve X4-025. The required schedule involves outage of the breaker every 6 years for trip checking and every 3-12 years for inspection (depending on the breaker type) with a typical duration of 1-2 days each assuming extensive corrections are not needed. These schedules could change if compliance requirements change. Sun Coke has the option of paying for a second, normally open breaker which would allow the maintenance outage of each breaker independently without the X4-025 facility experiencing an actual outage (estimate included). If this option is not chosen, the X4-025 customer interconnection facilities will be required to take periodic mandatory outages to facilitate the required maintenance outages of the single 138 kV breaker. During these outages the X4-025 generator will be unable to deliver to the PJM market.

Sun Coke will be solely responsible for all construction, permitting, power siting, maintenance, and other aspects of their proposed 138 kV line and other facilities. Sun Coke will own the proposed 138 kV line except AEP will own the final span of conductor entering the Millbrook Park station fence as well as any structures and facilities inside the station fence. If Sun Coke needs to interact with, change, relocate, or cross AEP owned lines when routing its new line to the designated delivery point, Sun Coke will need to coordinate its needs with AEP's transmission line engineering group. **Any estimates or design details in this study are <u>not</u> inclusive of any T-Line work outside of AEP's Millbrook Park station.**

Sun Coke is responsible for all costs associated with this connection. Costs of the Sun Coke station for 80 MW of generation and costs for line connection from the Sun Coke station (Customer Facility and Customer Interconnection Facilities) to AEP's Millbrook Park station are not included in this report. Costs for any potential requests for relocating AEP transmission line facilities to accommodate Sun Coke's new line are also not included in this report. If this project moves forward, Sun Coke will need to work with AEP's project manager, station engineering, and transmission line engineering departments to locate the exact point of interconnection and to coordinate any potential line routing conflicts.

The AEP construction scope includes:

- <u>Option #1</u> - Install new 138 kV breaker with associated equipment. **($463,600)**

- <u>Option #2</u> - Install two new 138 kV breakers (one N.C. and one N.O.) with associated equipment. **($765,100)**

- Either option requires a customer metering package. **($289,200)**

- Either option requires up to two transmission line structures to extend the customer's line from the station fence to the termination point in the proper 138 kV bay. **($75,000)**

- Replace the remote end relaying at Hillsboro 138kV station on the Millbrook Park circuit (either option). **($217,600)**

Total Attachment Facilities Cost:
Option #1 Estimated Cost: - $1,045,400
Option #2 Estimated Cost: - $1,346,900

Local AEP Impacts

The impact of the proposed generating facility on the AEP transmission system was assessed according to 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 Sun Coke project was studied as an 80 MW net energy injection consistent with the interconnection application. The results are summarized below.

Normal System (2017 Summer Conditions)

1. No problems identified

Single Contingency (2017 Summer Conditions)

2. No problems identified

Multiple Contingency (2017 Summer Conditions)

1. For a Millbrook Park 138 kV Bus #1 outage, the following facilities will be outaged:
    - Millbrook Park-North Portsmouth 138 kV line
    - Millbrook Park-Gavin 138 kV line

1 https://www.aep.com/about/codeofconduct/oasis/transmissionstudies/GuideLines/2012%20AEP%20PJM%20FERC%20715_Final_Part%204.pdf

2 https://www.aep.com/about/codeofconduct/OASIS/TransmissionStudies/Requirements/AEP_Interconnection_Requirements_rev0.pdf

- Breaker G, Millbrook Park-Argentum 138 kV – line remains energized from breaker E
- Millbrook Park-East Wheelersburg 138 kV line
- Millbrook Park T#5 138/69 kV transformer

This results in an overload on the Millbrook Park-North Haverhill-Argentum 69 kV circuit ranging from 101%-118%.

2. Millbrook Park-North Portsmouth 138 kV line & Millbrook Park T#5 138/69 kV transformer - This results in loading above 99% on the Millbrook Park-North Haverhill-Argentum 69 kV circuit.

Several other N-2 contingencies also exist which cause overload or near overload on the the Millbrook Park-North Haverhill-Argentum 69 kV circuit. Since these scenarios are more severe than the requirements of the PJM or AEP planning criteria, the customer will not be responsible for funding upgrades to mitigate these specific overloads. However, post-contingency load shedding and/or generation curtailment are options that may be employed by Operations to address these situations.

Short Circuit Analysis

See short circuit under Network Impacts below.

Stability Analysis

No problems identified.

Local Upgrades

See Network Upgrades below.

Network Impacts

The Queue Project #X4-025 was studied as an 80.0MW (Capacity 80.0 MW) injection at the Millbrook Park 138 kV substation in the AEP area. Project #X4-025 was evaluated for compliance with reliability criteria for summer peak conditions in 2015. Potential network impacts were as follows:

Generator Deliverability

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

No problems were identified.

Multiple Facility Contingency

(Double Circuit Tower Line contingencies only for the full energy output. Stuck breaker and bus fault contingencies will be performed for the Impact Study)

No problems were identified.

Short Circuit

1. Millbrook Park 138 kV circuit breaker H interrupting duty percentage increases from 85.4% to 106.8%.

2. Millbrook Park 138 kV circuit breaker O interrupting duty percentage increases from 97.3% to 114.2%.

3. Millbrook Park 138 kV circuit breaker M interrupting duty percentage increases from 76.0% to 91.5%.

Stability Analysis

Generation Interconnection Request X4-025 is for an 90 MW facility consisting of 1 x 90 MW coal fired steam turbine with a POI at Millbrook Park 138 kV Substation in the American Electric Power network.
X4-025 is now at the system impact study phase of PJM's Generation and Transmission Interconnection Process. This report describes a dynamic simulation analysis of X4-025 as part of the overall system impact study.
The load flow scenario for the analysis was the RTEP 2015 summer light load case, with the addition of the X4-025 models at maximum power output and leading power factor.
A total of 63 contingencies was studied, each with a 10 second simulation time period.
Studied faults included:

a) Steady state operation,
b) Three phase faults with normal clearing time,
c) Single phase faults with single phase stuck breaker,
d) Single phase faults with delayed clearing at remote end due to primary relaying failure.

X4-025 was modeled as per the Impact Study data supplied by the developer. For the intact system the fault simulations met the fault recovery criteria:

a) X4-025 was found to ride through the faults (except for faults where protective action tripped X4-025),
b) the system with X4-025 included was found to be transiently stable,
c) a new steady state was reached,
d) voltages at the POI and nearby buses returned to an acceptable range,
e) with system stability being maintained.

No reinforcements were found to be required. However, the power system stabilizer on Solid Unit A was disabled for this study, in order to eliminate a slightly negatively damped oscillation which was present prior to the addition of the X4-025 model.

Light Load Analysis

Not required.

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.

New System Reinforcements

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

- Replace Millbrook Park 138kV circuit breaker **H** (Network Upgrade #n1629) with a circuit breaker rated at 40kA and replace the applicable breaker controls and line relaying. Install a drop in control module. **($792,500)***

- Replace Millbrook Park 138kV circuit breaker **O** (Network Upgrade #n1628) with a circuit breaker rated at 40kA and replace the applicable breaker controls and line relaying. Install a drop in control module. **($792,500)***

Total Upgrade Facilities Cost: **$1,585,000***

* AEP is investigating making the circuit breaker replacements and associated upgrades part of a Transmission-Owner sponsored project. If pursued by AEP, the customer would not be responsible for these costs. Otherwise these costs will be the customer's responsibility.

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

MISO Impacts

PJM will determine if there are any impacts on MISO facilities in the Facilities study

Duke Integration

Evaluation of the impacts of the X4-025 project on the Duke transmission facilities recently integrated into PJM will be completed in the Facilities Study.

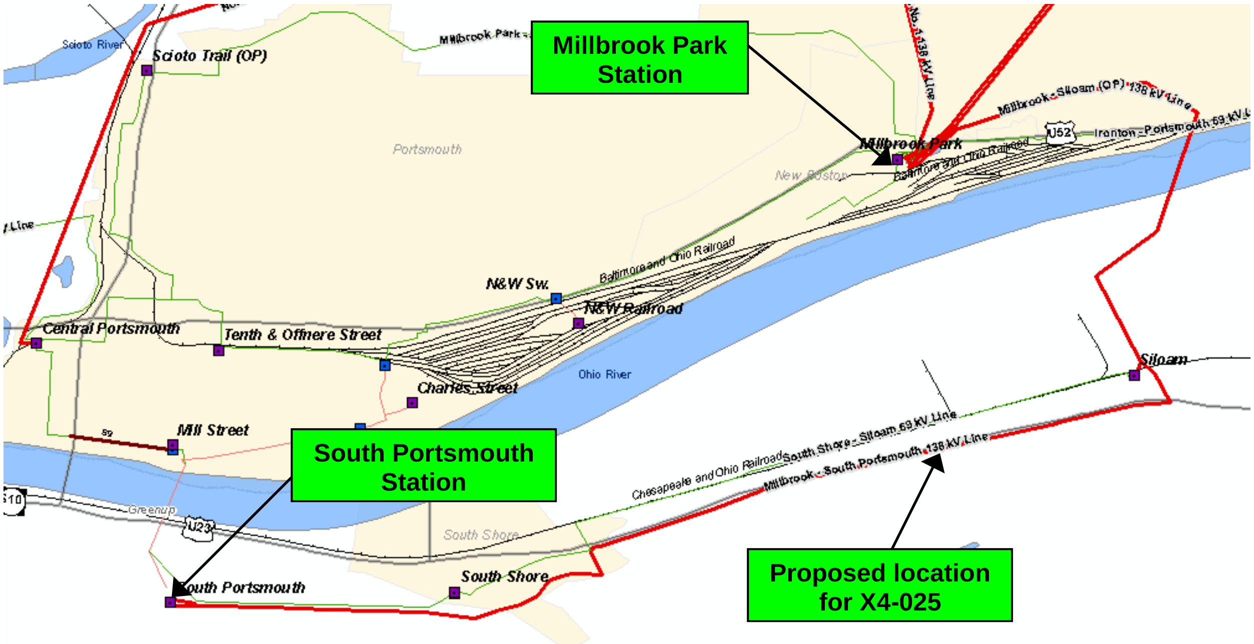
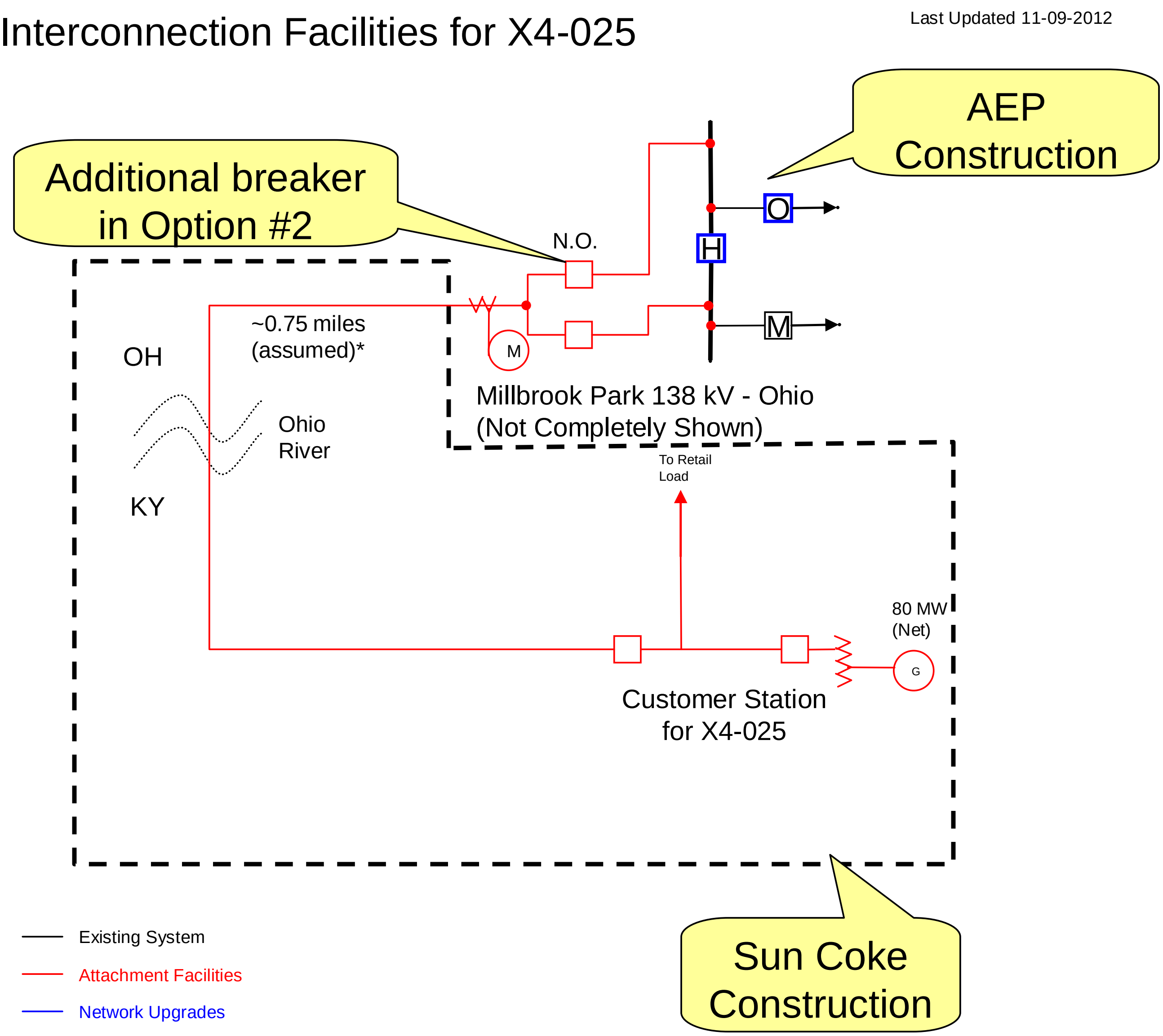


Exhibit 1: Approximate interconnection location of the proposed facilities

Interconnection Facilities for X4-025

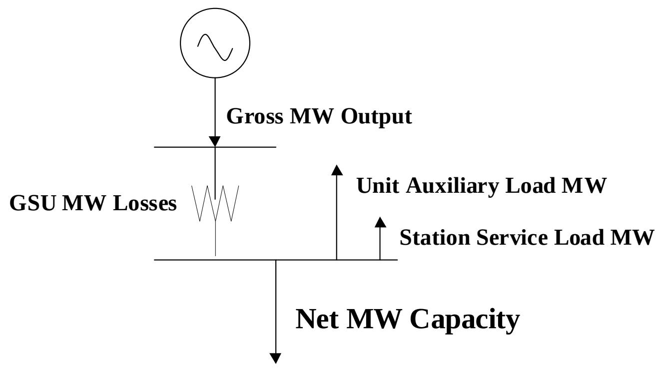


Notes:
*AEP will own the final span into Millbrook Park station. Sun Coke will construct/own all other new facilities outside of Millbrook Park station.

Exhibit 2: Simplified diagram of connection between X4-025 and Millbrook Park station. Diagram illustrates one possible configuration where both radial breakers are connected to different 138 kV buses.

Attachment #1

Unit Capability Data



Net MW Capacity = (Gross MW Output - GSU MW Losses* – Unit Auxiliary Load MW - Station Service Load MW)

Queue Letter/Position/Unit ID: ______________________________Queue X3-051 (ST1)

Primary Fuel Type: ____ Natural Gas

Maximum Summer (92º F ambient air temp.) Net MW Output**: ________________277

Maximum Summer (92º F ambient air temp.) Gross MW Output: ________________291

Minimum Summer (92º F ambient air temp.) Gross MW Output:_________________102

Maximum Winter (30º F ambient air temp.) Gross MW Output:__________________305

Minimum Winter (30º F ambient air temp.) Gross MW Output: _________________106

Gross Reactive Power Capability at Maximum Gross MW Output – Please include Reactive Capability Curve (Leading and Lagging): _150 MVAR lag, 100 MVAR lead

Individual Unit Auxiliary Load at Maximum Summer MW Output (MW/MVAR): .0001/.0001

Individual Unit Auxiliary Load at Minimum Summer MW Output (MW/MVAR): .0001/.0001

Individual Unit Auxiliary Load at Maximum Winter MW Output (MW/MVAR): .0001/.0001

Individual Unit Auxiliary Load at Minimum Winter MW Output (MW/MVAR): .0001/.0001

Station Service Load (MW/MVAR): _______________________________________ 14/10

* GSU losses are expected to be minimal.

** Your project's declared MW, as first submitted in Attachment N, and later confirmed or modified by the Impact Study Agreement, should be based on either the 92^{o} F Ambient

Air Temperature rating of the unit(s) or, if less, the declared Capacity rating of your project.

Queue Letter/Position/Unit ID: ___________________________________Queue X3-051

MVA Base (upon which all reactances, resistance and inertia are calculated): ______370

Nominal Power Factor:____ 0.85

Terminal Voltage (kV): ____21

Unsaturated Reactances (on MVA Base)

Direct Axis Synchronous Reactance, $X_{d(i)}$: ___________________________ 2.22

Direct Axis Transient Reactance, X'd(i): ____________________________ 0.286

Direct Axis Sub-transient Reactance, X"d(i): _________________________ 0.238

Quadrature Axis Synchronous Reactance, Xq(i): _______________________ 2.17

Quadrature Axis Transient Reactance, X'q(i): ________________________ 0.476

Quadrature Axis Sub-transient Reactance, X"q(i): _____________________ 0.238

Stator Leakage Reactance, Xl:_______________________________________ 0.211

Negative Sequence Reactance, X2(i): _______________________________ 0.238

Zero Sequence Reactance, X0: ____________________________________ 0.123

Saturated Sub-transient Reactance, X"d(v) (on MVA Base): __________________ 0.203

Armature Resistance, Ra (on MVA Base):________________________ 0.001 ohms/phase

Time Constants (seconds)

Direct Axis Transient Open Circuit, T'_{do}: ______________________________ 8.5

Direct Axis Sub-transient Open Circuit, T''_{do}:_ ________________________ 0.024

Quadrature Axis Transient Open Circuit, T'_{qo}:_ ___________________________ 1.8

Quadrature Axis Sub-transient Open Circuit, T''_{qo}: ______________________ 0.04

Inertia, H (kW-sec/kVA, on KVA Base): ___________________ 2.845 kw-sec/kva

Speed Damping, D:____

Saturation Values at Per-Unit Voltage [S(1.0), S(1.2)]:___________________ 0.164,0.578

Units utilize a GENROU Generator model

Unit GSU Data

Queue Letter/Position/Unit ID:___________________________________Queue X3-051

Generator Step-up Transformer MVA Base: _________________________________380

Generator Step-up Transformer Impedance (R+jX, or %, on transformer MVA Base):0.0001+j.09

Generator Step-up Transformer Reactance-to-Resistance Ration (X/R):_______________

Generator Step-up Transformer Rating (MVA): ___________________ OA/FA/FA 380

Generator Step-up Transformer Low-side Voltage (kV):_________________________21

Generator Step-up Transformer High-side Voltage (kV): _______________________765

Generator Step-up Transformer Off-nominal Turns Ratio: _________________________

Generator Step-up Transformer Number of Taps and Step Size:+/-5% in 2.5% steps on HS

Unit Capability Data

X4-025 Project Data

A. Project capability data

	1 Unit / Total
Max Summer Gross MW Output	90
Individual Unit Aux Load Max Summer Output	10 / 7.7
Station Service Load	*
Max Summer Net MW Output	80
Min Summer Gross MW Output	44
Individual Unit Aux Load Min Summer Output	10 / 7.7
Station Service Load	*
Min Summer Net MW Output	34
Max Winter Gross MW Output	90
Individual Unit Aux Load Max Winter Output	10 / 7.7
Station Service Load	*
Max Winter Net MW Output	80
Min Winter Gross MW Output	44
Individual Unit Aux Load Min Summer Output	10 / 7.7
Station Service Load	*
Min Winter Net MW Output	34
Reactive Power	See D-Curve

Project Capability Comments:

1) Based on data provided, station service load and individual unit aux load were assumed to be the same.

B. GSU Data

	Revised (6/15/12)
MVA Base	75
Ratings (OA/FFA/FFA)	75 / 100 / 125
Impedance (Z)	j0.08
X/R	50
Low-side voltage (kV)	13.8
High-side voltage (kV)	138
Low-voltage winding connection (Wye, Delta, etc.)	Delta
High-voltage winding connection (Wye, Delta, etc.)	Wye Grounded

C. Line Data

MVA Base	100
Voltage Level (kV)	138
Line Length (mi)	0.75
Pos Impedance (Z) in PU/mile	0.000578 + j0.003818
Zero Impedance (Z) in PU/mile	0.000249 + j0.010820
Susceptance	0.00112

D. Generator Model: GENROU

Number of Machines: 1
MVA Base: 106.82 MVA
Nominal: 0.85
Terminal Voltage: 13.8 kV

GENROU Model

CONs	Value (Revised)	Description
J	8.304	T'do
J+1	0.044	T"do
J+2	2.5	T'qo
J+3	0.15	T"qo
J+4	3	H
J+5	0	D
J+6	2.41	Xd
J+7	2.29	Xq
J+8	0.265	X'd
J+9	0.47	X'q
J+10	0.179	X"d=X"q
J+11	0.0141	Xl
J+12	0.12	S(1.0)
J+13	0.564	S(1.2)

E. Excitation System Model: IEEE AC7B

Value	Description
0.02	**TR**
47.61	**KPR**
95.22	**KIR**
0.00	**KDR**
9999	**TDR**
26.19	**VRMAX**
0.00	**VRMIN**
4.59	**KPA**
22.93	**KIA**
34.94	**VAMAX**
-34.94	**VAMIN**
0	**KP**
10	**KL**
0	**KF1**
1.0	**KF2**
0	**KF3**
9999	**TF**
0.38	**KC**
3.64	**KD**
1.00	**KE**
0.90	**TE**

Value	Description
26.19	**VFEMAX**
0.00	**VEMIN**
19.72	**E1**
0.33	**S(E1)**
17.55	**E2**
0.31	**S(E2)**

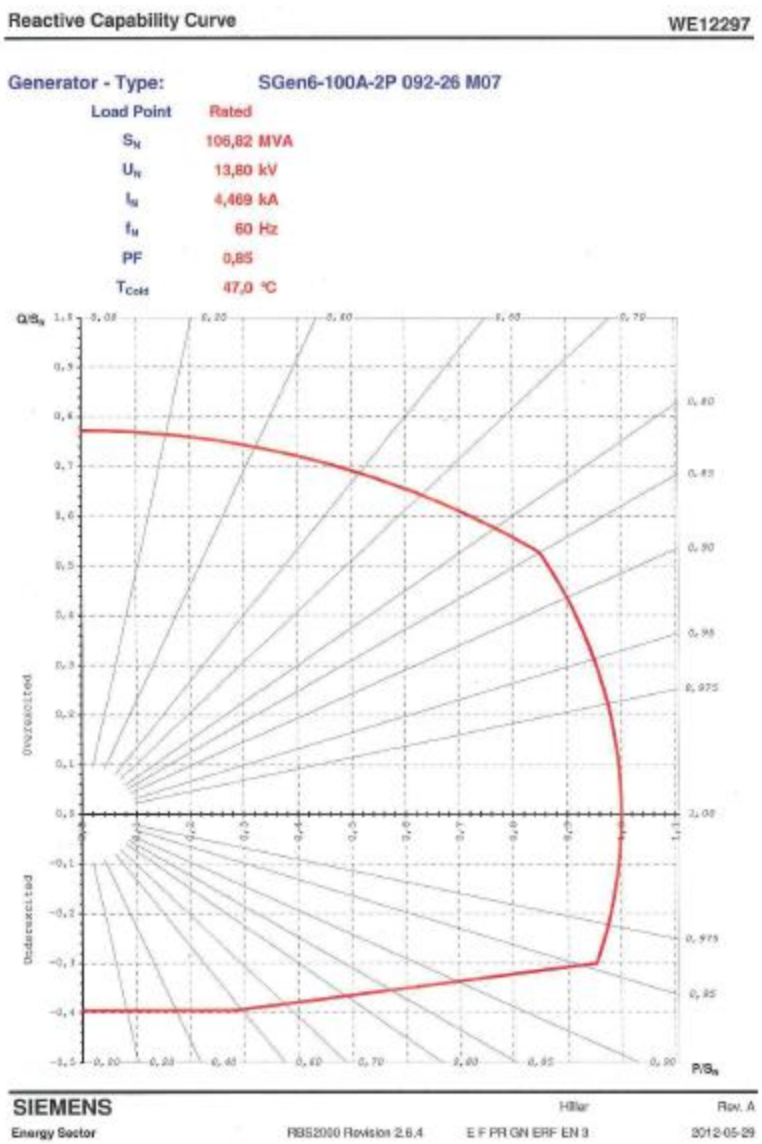
F. Governor Model: IEEEG1.

IEEEG1	Parameter
K	20
T1	60
T2	20
T3	0.3
Uo	0.25
Uc	-3.3
PMax	1.01
PMin	0
T4	0.011
K1	1
K2	0
T5	0
K3	0

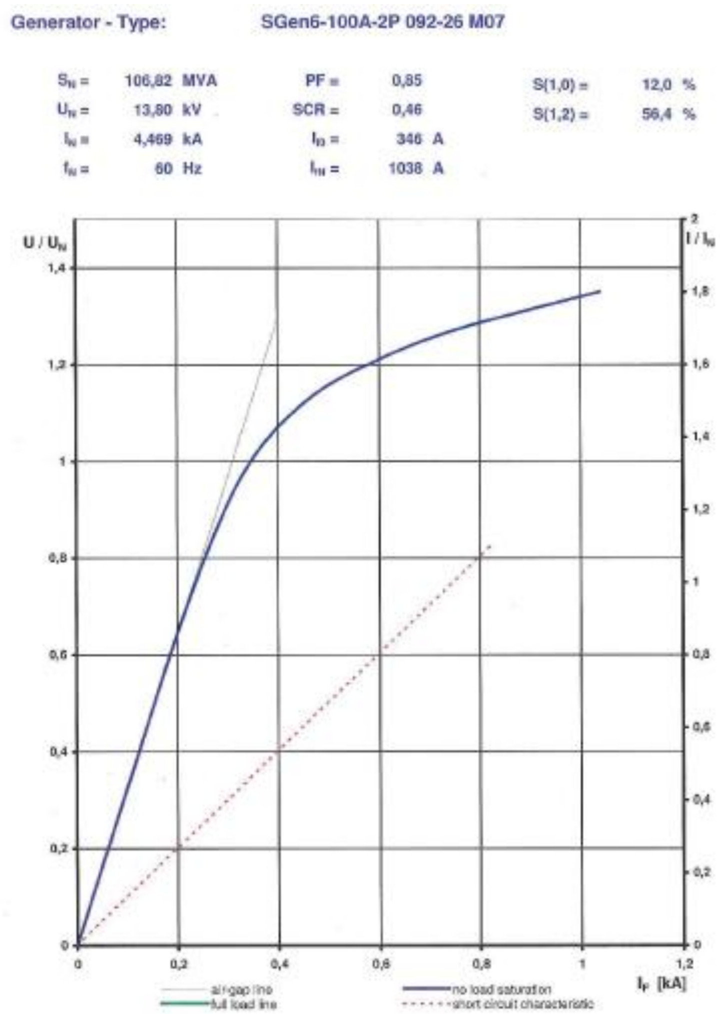
K4	0
T6	0
K5	0
K6	0
T7	0
K7	0
K8	0

G. Power System Stabilizer (PSS) Model: **Not provided. Indicated as not available.**

H. Design Capability Curve (D-Curve): Provided.



I. Saturation Curve: Provided.



Appendix 2

1. Description of the Project

The proposed X4-025 project is specified in the Impact Study data provided in Attachment 1. Attachment 2 shows the one line diagram of the AEP network in the vicinity of X4-025.

X4-025 is connected to the AEP system via the exsisting Millbrook Park 138 kV Substation which will be expanded to accommodate the connection of X4-025.

Figure 1 shows how X4-025 has been modeled in this study. Table 1 lists the parameters given in the impact study data and the corresponding parameters of the X4-025 loadflow model. Attachment 3 provides a diagram of the PSS/E model in the vicinity of X4-025; Attachment 4 gives the X4-025 PSS/E loadflow model.

The dynamic models for the X4-025 plant are based on standard PSS/E library models as well as user models provided by PJM.

Figure 1. X4-025 Plant Model

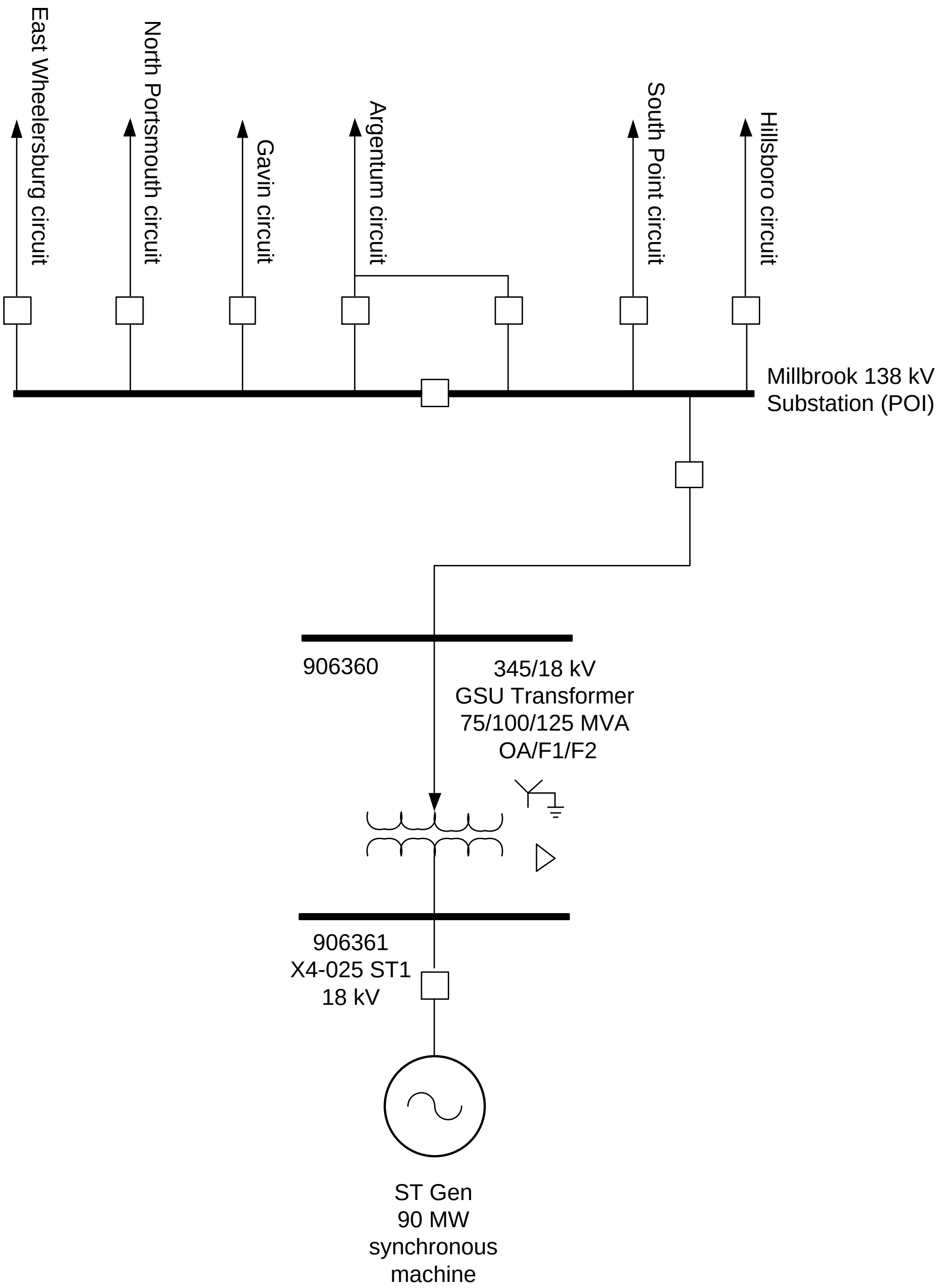


Table 1: X4-025 Plant Model

	Impact Study Data[3]	Model
Steam turbine		
Generator	1 x 90 MW ST +56.6 / -33.1 MVAr Vt = 13.8 kV Unsaturated reactance, pu @ 106.82 MVA: X''d(i) = 0.179 X''q(i) = 0.179	1 x 90 MW ST MBASE 106.82 MVA PMAX 90 MW PMIN 0 MW QMAX 56.6 MVAr QMIN -33.1 MVAr XSORCE 0.179 pu Dynamic data as included in Attachment 5
GSU transformer	1 x 75/100/125 MVA OA/F1/F2 138 / 13.8 kV Ynd 0.16 % + j 8.00 % @ 75 MVA	1 x 75 MVA 138 / 13.8 kV Ynd 0.16 % + j 8.00 % @ 75 MVA
Transmission line	MVA Base 100 MVA Line Length 0.75 miles Impedance 0.000578 + j0.003818 pu / mi Susceptance 0.00112 pu / mile	MVA Base 100 MVA R + jX 0.000434 + j0.002864 pu B 0.00084 pu
Station service load	Not specified	N/A

[3] Winter ratings are used in the modeling.

2. Loadflow and Dynamics Case Setup

The dynamics simulation analysis was carried out using PSS/E Version 30.3.1.
The load flow scenario and fault cases for this study are based on PJM's Region Transmission Planning Process[4] and discussions with PJM.
The selected load flow scenario is the RTEP 2015 summer light load case, provided by PJM from the W3-088 study, with the following modifications:

a) Modeling of X4-025 at Millbrook Park 138 kV Substation
b) Removal of withdrawn and subsequent queue projects in the vicinity of X4-025
c) Connection and disconnection of some distant generation units in the PJM system in order to maintain slack units within limits
d) Deactivation of bus 243462 (an AEP 242 kV bus connected only to a transformer and solving at > 1.4 pu voltage) to improve loadflow convergence
e) Deactivation of 05SOLIDA Unit 1 power system stabilizer due to negatively damped oscillations during fault conditions

In the load flow, the X4-025 generator is set to maximum power output (90 MW), 0.95 pu terminal voltage, and leading power factor.
Generation within the PJM500 system (area 225 in the PSS/E case) and within a 4 bus radius of X4-025 has been dispatched online at maximum output (P_{MAX}) – exceptions to this and the reason for them are listed in Table 2.

[4] Manual 14B: PJM Region Transmission Planning Process, Rev 19, September 15 2011, Attachment G : PJM Stability, Short Circuit, and Special RTEP Practices and Procedures.

Table 2: Generation at reduced output within 4-bus radius of X4-025

Bus	Name	Unit	PGEN (MW)	PMAX (MW)	Reason
242807	05SPORNA 138.00	5	35	42	Conflict with governor model, PMAX not achieveable
242807	05SPORNA 138.00	6	35	42	
242807	05SPORNA 138.00	7	35	42	
242807	05SPORNA 138.00	8	35	42	
243084	05RUTLAN 138.00	1	37.48	42	Conflict with governor model, PMAX not achieveable
246759	05SOLIDA 138.00	1	172	185	Conflict with governor model, PMAX not achieveable
242931	05BEVERL 345.00	1A	176	216.667	Conflict with governor model, PMAX not achieveable
242931	05BEVERL 345.00	1B	176	216.667	
242940	05MUSKNG 345.00	5	589	600	Conflict with governor model, PMAX not achieveable
242947	05WATERF 345.00	1A	185	227.5	Conflict with governor model, PMAX not achieveable
242947	05WATERF 345.00	1B	185	227.5	
242947	05WATERF 345.00	1C	151	227.5	
270000	20FOOTHL 345.00	1	171	191	Conflict with governor model, PMAX not achieveable
270000	20FOOTHL 345.00	2	171	191	
270001	20ZELDA 345.00	1	171	191	
270001	20ZELDA 345.00	2	171	191	
270001	20ZELDA 345.00	3	171	191	
243187	05GVG2 26.000	2H	657.2	667	Conflict with governor model, PMAX not achieveable
243187	05GVG2 26.000	2R	650.6	653	
243764	05BSG1 22.000	1	263	280	Conflict with governor model, PMAX not achieveable
248000	06CLIFTY 345.00	6	73.26	623.7001	Dynamic data, summer peak case and publicly available information suggest this machine is identical size to units 1-5
248000	06CLIFTY 345.00	A	110	124.715	Conflict with governor model, PMAX not achieveable
248000	06CLIFTY 345.00	B	110	124.715	
248000	06CLIFTY 345.00	C	124.74	623.7001	Dynamic data, summer peak case and publicly available information suggest this machine is identical size to units 7-B

In order to achieve an acceptable voltage profile across the 765 kV network, the 765 kV line shunt reactors listed in Table 3 were switched out of service.

Table 3: 765 kV Line shunt reactors switched out

From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Line B From (pu on 100 MVA) Removed	Line B To (pu on 100 MVA) Removed
242510	05BAKER 765.00	242511	05BROADF 765.00	1	-3	-3
242924	05HANG R 765.00	243208	05JEFRSO 765.00	1	-3	-3
243207	05GRNTWN 765.00	243208	05JEFRSO 765.00	1	-3	-3
242509	05AXTON 765.00	242514	05J.FERR 765.00	1	-3	0
242512	05CLOVRD 765.00	242514	05J.FERR 765.00	1	-3	0
242512	05CLOVRD 765.00	242515	05JOSHUA 765.00	1	-3	0
243208	05JEFRSO 765.00	243209	05ROCKPT 765.00	1	-1.5	-1.5
243209	05ROCKPT 765.00	243210	05SULLVA 765.00	1	-1.5	-1.5
242511	05BROADF 765.00	242514	05J.FERR 765.00	1	-1.5	0
242513	05CULLOD 765.00	242517	05WYOMIN 765.00	1	0	-3
242928	05MARYSV 765.00	243206	05DUMONT 765.00	1	-3	-3
242508	05AMOS 765.00	242929	05NPROCT 765.00	1	-1.5	0
242922	05FLTLCK 765.00	242923	05GAVIN 765.00	1	0	-3
242922	05FLTLCK 765.00	242928	05MARYSV 765.00	1	0	-3
242926	05MALIS 765.00	242928	05MARYSV 765.00	1	0	-3
242920	05BELMON 765.00	242925	05KAMMER 765.00	1	0	-3

Modifications were made to the dynamics case to resolve initialization issues:

1. Removal of several distant generation units from the dynamic simulation to avoid initialization problems.

2. For bus 270000 existing units 1, 2 & 3 and bus 270001 existing units 1 & 2, the saturation factors S(1.0) and S(1.2) were much higher than expected; it was assumed they are % rather than per unit values. These values were thus divided by 100 to set more realistic values.

3. For bus 248000 machine C (+ machine 6), the IEEEG1 governor model was suppressed to avoid initializing out of limits.

Additionally, the power system stabilizer for Unit 1 at Solid (bus 246759) has been removed from the dynamic simulation in order to resolve a negatively damped rotor angle oscillation evident for that unit. This oscillation was present with and without X4-025 and therefore is not attributable to X4-025.

3. Fault Cases

Tables 4 – 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. Faults were applied to transmission circuits and transformers connected to the Point of Interconnection or one bus removed[5] (up to two buses removed for delayed (Zone 2) clearing faults).

The studied faults included :

a) Steady state operation
b) Three phase faults with normal clearing time
c) Single phase faults with single phase stuck breaker
d) Single phase to ground faults with delayed clearing at remote end due to primary relaying failure

The one line diagram of the AEP network in Attachment 2 shows where faults were applied.

The positive sequence fault impedances for single line to ground faults were derived from a separate short circuit case provided by PJM, modified by PSC to ensure that connected generators in the vicinity of X4-025 have not withdrawn from the PJM queue, and are not greater than the queue position under study.

4. Fault Recovery Criteria

The fault recovery criteria applicable to this study are as per PJM's Region Transmission Planning Process:

a) Post-contingency voltages should remain within +/- 0.05 pu of the pre-contingency voltages at transmission level buses.
b) Post-contingency oscillations should be positively damped with a damping margin of at least 3%.
c) The X4-025 generator should maintain its pre-contingent power output following the fault.

5. Summary of Results

Plots from the dynamic simulations are provided in Attachment 6, with results summarized in Tables 2 – 5.
The fault simulations met the fault recovery criteria:

- the system with X4-025 included was found to be transiently stable,
- a new steady state was reached,
- voltages at the POI and nearby buses returned to an acceptable range,
- with X4-025 riding through the fault (except for faults where protective action tripped X4-025) and system stability being maintained.

[5] One bus removed from the POI refers to buses with transmission circuit breakers, not tee-offs or buses with only supply circuit breakers.

Table 4. Steady State Operation

Fault ID	Duration	X4-025 No Mitigation
SS.01	Steady state 20 sec	Stable

Table 5.Three-phase Faults with Normal Clearing

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	X4-025 No Mitigation
3N.01	Fault at Millbrook Park 138 kV on X4-025 circuit. Trips X4-025.	4.5 / 4.5	(Trips X4-025)
3N.02	Fault at Millbrook Park 138 kV on South Point circuit	4.5 / 4.5	Stable
3N.03	Fault at Millbrook Park 138 kV on Gavin circuit	4.5 / 4.5	Stable
3N.04	Fault at Millbrook Park 138 kV on North Portsmouth circuit	4.5 / 4.5	Stable
3N.05	Fault at Millbrook Park 138 kV on Sinking Springs - Hillsboro circuit	4.5 / 4.5	Stable
3N.06	Fault at Millbrook Park 138 kV on Dogwood Ridge - East Wheelersburg circuit	4.5 / 4.5	Stable
3N.07	Fault at Argentum 138 kV on South Portsmouth Metering Station - Millbrook Park circuit	4.5 / 4.5	Stable
3N.08	Fault at South Point 138 kV on Millbrook Park circuit	4.5 / 4.5	Stable
3N.09	Fault at South Point 138 kV on Fayette - Scottown Switch - Apple Grove circuit	4.5 / 4.5	Stable
3N.10	Fault at South Point 138 kV on North Proctorville circuit	4.5 / 4.5	Stable
3N.11	Fault at South Point 138 kV on Kenova - Tri State circuit.	4.5 / 4.5	Stable
3N.12	Fault at Gavin 138 kV on Millbrook Park circuit	4.5 / 4.5	Stable
3N.13	Fault at Gavin 138 kV on Lakin - Sporn circuit	4.5 / 4.5	Stable
3N.14	Fault at Gavin 138 kV on Sporn circuit	4.5 / 4.5	Stable
3N.15	Fault at Gavin 138 kV on Addison - Thivener Switch - North Crown City - Windsor - North Proctorville circuit	4.5 / 4.5	Stable
3N.16	Fault at North Portsmouth 138 kV on Millbrook Park circuit.	4.5 / 4.5	Stable
3N.17	Fault at North Portsmouth 138 kV on Central Portsmouth circuit	4.5 / 4.5	Stable

3N.18	Fault at North Portsmouth 138 kV on South Lucasville - Wakefield - Don Marquis circuit.	4.5 / 4.5	Stable
3N.19	Fault at Hillsboro 138 kV on Sinking Springs - Millford circuit	4.5 / 4.5	Stable
3N.20	Fault at Hillsboro 138 kV on Middleboro - Hutchings circuit	4.5 / 4.5	Stable
3N.21	Fault at Hillsboro 138 kV on Emerald - Kenton circuit	4.5 / 4.5	Stable
3N.22	Fault at Hillsboro 138 kV on Warren circuit	4.5 / 4.5	Stable
3N.23	Fault at East Wheelersburg 138 kV on Dogwood Ridge - Millbrook Park circuit	4.5 / 4.5	Stable
3N.24	Fault at East Wheelersburg 138 kV on Hanging Rock - Bellefonte circuit	4.5 / 4.5	Stable

Table 6. Single-phase Faults with Stuck Breaker

Fault ID	Fault description	Clearing Time Normal / Stuck Breaker (Cycles)	X4-025 No Mitigation
1B.01	Fault at Millbrook Park 138 kV on X4-025 circuit. Trips X4-025. Breaker stuck. Fault cleared with loss of all Millbrook Park 138 kV Bus 2 circuits.	4.5 / 17	Stable (Trips X4-025)
1B.02	Fault at Millbrook Park 138 kV on South Portsmouth - Argentum circuit. Breaker E stuck. Fault cleared with loss of all Millbrook Park 138 kV Bus 2 circuits. Trips X4-025.	4.5 / 17	Stable (Trips X4-025)
1B.03	Fault at Millbrook Park 138 kV on South Point circuit. Breaker stuck. Fault cleared with loss of all Millbrook Park 138 kV Bus 2 circuits. Trips X4-025.	4.5 / 17	Stable (Trips X4-025)
1B.04	Fault at Millbrook Park 138 kV on Gavin circuit. Breaker stuck. Fault cleared with loss of all Millbrook Park 138 kV Bus 1 circuits.	4.5 / 17	Stable
1B.05	Fault at Millbrook Park 138 kV on North Portsmouth circuit. Breaker stuck. Fault cleared with loss of all Millbrook Park 138 kV Bus 1 circuits.	4.5 / 17	Stable
1B.06	Fault at Millbrook Park 138 kV on Sinking Springs - Hillsboro circuit. Breaker stuck. Fault cleared with loss of all Millbrook Park 138 kV Bus 2 circuits. Trips X4-025.	4.5 / 17	Stable (Trips X4-025)
1B.07	Fault at Millbrook Park 138 kV on Dogwood Ridge - East Wheelersburg circuit. Breaker stuck. Fault cleared with loss of all Millbrook Park Bus 1 circuits.	4.5 / 17	Stable
1B.08	Fault at South Point 138 kV on Millbrook Park circuit. Breaker stuck. Fault cleared with loss of all South Point 138 kV Bus 1 circuits.	4.5 / 17	Stable
1B.09	Fault at South Point 138 kV on Fayette - Scottown Switch - Apple Grove circuit. Breaker Stuck. Fault cleared with loss of all South Point 138 kV Bus 2 circuits.	4.5 / 17	Stable
1B.10	Fault at South Point 138 kV on North Proctorville circuit. Breaker stuck. Fault cleared with loss of all South Point 138 kV Bus 2 circuits.	4.5 / 17	Stable
1B.11	Fault at South Point 138 kV on Kenova - Tri State circuit. Breaker stuck. Fault cleared with loss of all South Point 138 kV Bus 1 circuits.	4.5 / 17	Stable
1B.12	Fault at Gavin 138 kV on Millbrook Park circuit. Breaker stuck to Sporn 1 (Lakin) circuit. Fault cleared with loss of Sporn 1 (Lakin) circuit.	4.5 / 17	Stable
1B.13	Fault at Gavin 138 kV on Sporn 1 (Lakin) circuit. Breaker AE stuck to Millbrook Park circuit. Fault cleared with loss of Millbrook Park circuit.	4.5 / 17	Stable
1B.14	Fault at Gavin 138 kV on Addison - Thivener Switch - North Crown City - Windsor circuit. Breaker AC stuck. Cleared with loss of IAAS circuit.	4.5 / 17	Stable
1B.15	Fault at North Portsmouth 138 kV on Millbrook Park circuit. Breaker D stuck. Fault cleared with loss of all North Portsmouth 138 kV circuits.	4.5 / 17	Stable

1B.16	Fault at North Portsmouth 138 kV on South Lucasville - Wakefield - Don Marquis circuit. Breaker C stuck. Fault cleared with loss of all North Portsmouth 138kV circuits.	4.5 / 17	Stable
1B.17	Fault at Hillsboro 138 kV on Sinking Springs - Millbrook Park circuit. Breaker stuck. Fault cleared with loss of all Hillsboro 138 kV circuits.	4.5 / 17	Stable
1B.18	Fault at Hillsboro 138 kV on Middleboro - Hutchings circuit. Breaker stuck. Fault cleared with loss of all Hillsboro 138 kV circuits.	4.5 / 17	Stable
1B.19	Fault at Hillsboro 138 kV on Emerald - Kenton circuit. Breaker stuck. Fault cleared with loss of all Hillsboro 138 kV circuits.	4.5 / 17	Stable
1B.20	Fault at Hillsboro 138 kV on Warren circuit. Breaker stuck. Fault cleared with loss of all Hillsboro 138 kV circuits.	4.5 / 17	Stable
1B.21	Fault at East Wheelersburg 138 kV on Dogwood Ridge - Millbrook Park circuit. Breaker stuck. Fault cleared with loss of all East Wheelersburg 138 kV circuits.	4.5 / 17	Stable
1B.22	Fault at East Wheelersburg 138 kV on Hanging Rock - Bellefonte circuit. Breaker stuck. Fault cleared with loss of all East Wheelersburg 138 kV circuits.	4.5 / 17	Stable

Table 7. Single-phase Faults with Delayed Clearing at Remote End

Fault ID	Fault description	Clearing time Near / Remote end (cycles)	X4-025 No Mitigation
1D.01	Fault at X4-025. Delayed clearing at Millbrook Park. Trips X4-025.	4.5 / 60	Stable (Trips X4-025)
1D.02	Fault at Millbrook Park 138 kV on South Point circuit. Delayed clearing at South Point.	4.5 / 60	Stable
1D.03	Fault at Millbrook Park 138 kV on Gavin circuit. Delayed clearing at Gavin.	4.5 / 60	Stable
1D.04	Fault at Millbrook Park 138 kV on North Portsmouth circuit. Delayed clearing at North Portsmouth.	4.5 / 60	Stable
1D.05	Fault at Millbrook Park 138 kV on Sinking Springs - Hillsboro circuit. Delayed clearing at Hillsboro.	4.5 / 60	Stable
1D.06	Fault at Millbrook Park 138 kV on Dogwood Ridge - East Wheelersburg circuit. Delayed clearing at East Wheelersburg.	4.5 / 60	Stable
1D.07	Fault at Argentum 138 kV on South Portsmouth Metering Station - South Portsmouth - Millbrook Park circuit.	4.5 / 60	Stable
1D.08	Fault at South Point 138 kV on Millbrook Park circuit. Delayed clearing at South Point.	4.5 / 60	Stable
1D.09	Fault at North Proctorville 138 kV on South Point circuit. Delayed clearing at South Point.	4.5 / 60	Stable
1D.10	Fault at Gavin 138 kV on Millbrook Park circuit. Delayed clearing at Millbrook Park.	4.5 / 60	Stable
1D.11	Fault at Gavin 138 kV on Sporn 2 circuit. Delayed clearing at Sporn.	4.5 / 60	Stable
1D.12	Fault at North Portsmouth 138 kV on Millbrook Park circuit. Delayed clearing at Millbrook Park.	4.5 / 60	Stable
1D.13	Fault at Don Marquis 138 kV on Wakefield - South Lucasville - North Portsmouth circuit. Delayed clearing at North Portsmouth.	4.5 / 60	Stable
1D.14	Fault at Hillsboro 138 kV on Sinking Springs - Millford Park circuit. Delayed clearing at Millbrook Park.	4.5 / 60	Stable
1D.15	Fault at Hillsboro 138 kV on Middleboro - Hutchings circuit. Delayed clearing at Hutchings.	4.5 / 60	Stable
1D.16	Fault at East Wheelersburg 138 kV on Dogwood Ridge - Millbrook Park circuit. Delayed clearing at Millbrook Park.	4.5 / 60	Stable