Generation Interconnection System Impact Study Report

For

PJM Generation Interconnection Request Queue Position Y3-068

Washington 138 kV

June 2014

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 project developer 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

Moundsville Power, LLC proposes to install PJM Project #Y3-068, a 525 MW (525 MW Capacity) natural gas generating facility (2x1 Combined Cycle) to the American Electric Power (AEP) transmission system. The point of interconnection requested is a direct connection to the George Washington 138 kV station via two (2) 138 kV breakers (See Figure 1). The location of the natural gas generating facility is in Moundsville, WV (See Figure 2).

The requested in-service date is June 1, 2018.

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.

George Washington 138kV Station Proposed Layout

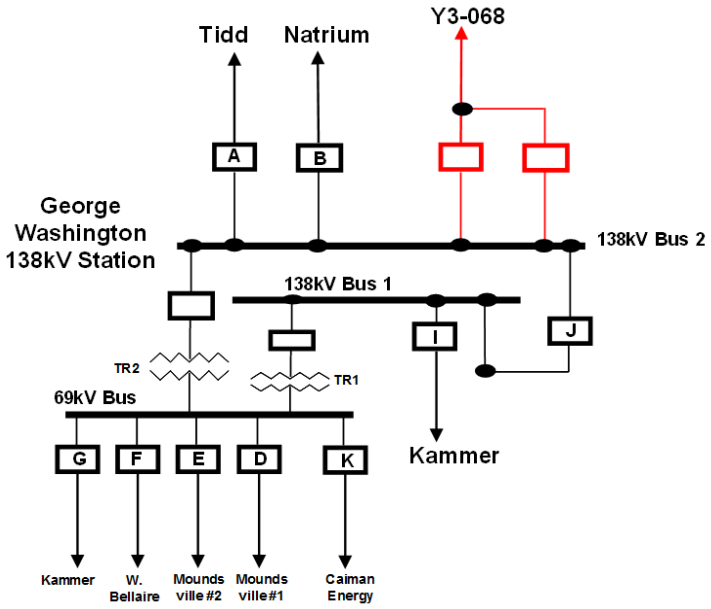

Figure 1

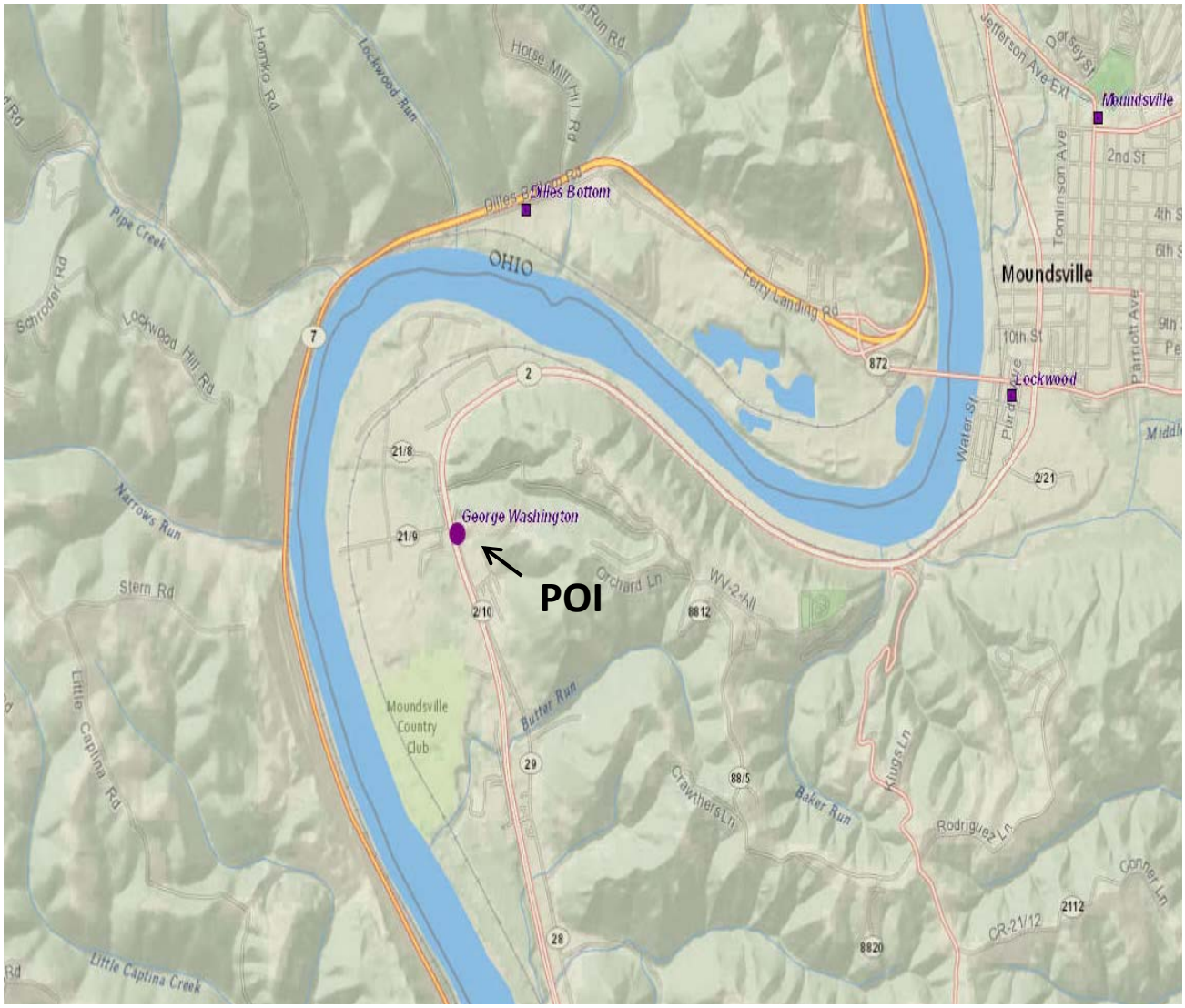

Figure 2

Cost Summary

The Y3-068 project will be responsible for the following costs:

Description	Total Cost
George Washington 138 kV Station Cost	$1,569,700
Protection and Relaying Cost	$121,340
New System reinforcements – Generator Deliverability (Table 2b)	$11,413,600
New System reinforcements - Multiple Facility (Table 3b)	$3,099,500
Circuit Breakers (Table 4b)	$1,600,000
Total Costs	**$17,804,140**

Table 1 – Cost Summary

Attachment Facilities

Direct Connection into the George Washington 138 kV Station:

Direct connection to the George Washington 138 kV station will require two (2) 138 kV circuit breakers. Protection schemes will need to be modified and 138 kV metering will need to be installed.

The following work is required to connect Project Y3-068:

George Washington 138 kV Station Cost:

- Install two (2) new 138 kV circuit breakers to connect the proposed generation. SCADA, 138 kV revenue metering, and associated equipment will also need to be installed. Estimated Cost: $1,569,700. **Network Upgrade n4200**

Protection and Relaying Cost:

- Line protections and controls at the existing George Washington 138 kV station will need to be upgraded. Estimated Cost: $121,340. **Network Upgrade n4201**

Revenue Metering and SCADA Requirements

PJM Requirements

The Interconnection Customer will be required to install equipment necessary to provide Revenue Metering (KWH, KVARH) and real time data (KW, KVAR) for IC's generating Resource. See PJM Manuals M-01 and M-14D, and PJM Tariff Sections 24.1 and 24.2.

Metering Equipment Installation at the Point of Interconnection

Installation of revenue grade metering equipment will be required at the Y3-068 point of interconnection. Suitable metering must be installed by AEP as well as the developer and will be determined in the Facility Study. All metering equipment must meet applicable AEP tariff requirements as well as being compliant with all applicable requirements of the PJM agreements. The equipment must provide bi-directional revenue metering (KWH and KVARH) and real-time data (KW, KVAR, circuit breaker status, and generator bus voltages) for the developer's generating resource.

The developer is also required to provide revenue metering (KWH and KVARH) and real-time telemetry data (KW, KVAR, and KV) to PJM in compliance with the requirements listed in PJM Manuals M-01 and M-14.

Network Impacts

The Queue Project Y3-068 was studied as a 525.0 MW (Capacity 525.0 MW) injection into the George Washington 138 kV substation in the AEP area. Project Y3-068 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project Y3-068 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Generator Deliverability

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

Generator Deliverability											
	Contingency			Bus		Loading		Rating		MW	FG
#	Type	Name	Facility Description	From	To	Initial	Final	Type	MVA	Contrib.	App.
1	N-1	ADD_GW_BUSTIE	05G WASH 138/69 kV transformer	243012	245935	5.69	104.08	ER	175	170.7	6
2	N-1	5213_B2_TOR773	DILLES-SHADYSID 69 kV line	245086	245098	33.49	112.06	ER	46	37.71	9
3	N-1	5213_B2_TOR773	GLENDALE-BRUES 69 kV line	245937	245920	24.35	115.73	ER	48	46.53	10

Table 2a

Multiple Facility Contingency

(Double Circuit Tower Line contingencies were studied for the full energy output. The contingencies of Line with Failed Breaker and Bus Fault will be performed for the Impact Study.)

Multiple Facility Contingency											
	Contingency			Bus		Loading		Rating		MW	FG
#	Type	Name	Facility Description	From	To	Initial	Final	Type	MVA	Contrib.	App.
1	DCTL	4743	05TILTON-WINDSOR 138 kV line	243131	235428	94.35	102.66	ER	284	27.78	4
2	LFFB	4743_C2	05TILTON-WINDSOR 138 kV line	243131	235428	94.35	102.66	ER	284	27.78	5
3	BUS	ADD_GW2	05G WASH 138/69 kV transformer	243012	245935	23.58	104.37	ER	175	142.7	7

Table 3a

Short Circuit

(Summary of impacted circuit breakers)

New circuit breakers found to be over-duty:

BUS_NO	BUS	BREAKER	Rating Type	Duty Percent With Y3-068 AEP	Duty Percent Without Y3-068 AEP	Duty Percent Difference
1045	05NATRIU 138.kV	I	T	110.50%	105.50%	5.00%
1045	05NATRIU 138.kV	K	T	109.70%	104.70%	5.00%

Table 4a

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.

Steady-State Voltage Requirements

(Summary of the VAR requirements based upon the results of the steady-state voltage studies)

None

Stability and Reactive Power Requirement for Low Voltage Ride Through

(Summary of the VAR requirements based upon the results of the dynamic studies)

See Appendix 11 at the end of this report

New System Reinforcements

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

Generator Deliverability						
#	Type	Name	Facility Description	Mitigation	Network Upgrade Number	Cost
1	N-1	ADD_GW_BUSTIE	05G WASH 138/69 kV transformer	Replace the George Washington 138/69 kV TR #2.	n4205	$1,940,900
2	N-1	5213_B2_TOR773	DILLES-SHADYSID 69 kV line	Rebuild the entire 5.83 mile section of DILLES - SHADYSID 69 kV line	n4206	$5,797,700
3	N-1	5213_B2_TOR773	GLENDALE-BRUES 69 kV line	Rebuild the entire 5.02 mile section of Glendale- Brues 69 kV	n4207	$3,675,000
						$11,413,600

Table 2b

Multiple Facility Contingency						
#	Type	Name	Facility Description	Mitigation	Network Upgrade Number	Cost
1	DCTL	4743	05TILTON-WINDSOR 138 kV line	Rebuild entire 4.14 miles of the Tilton – Windsor 138 kV line - (ACSR 556.5 26/7 Dove conductor section 1)	n4208	$3,099,500
2	LFFB	4743_C2	05TILTON-WINDSOR 138 kV line	Rebuild entire 4.14 miles of the Tilton – Windsor 138 kV line - (ACSR 556.5 26/7 Dove conductor section 1)	N/A	Same as 3b
3	BUS	ADD_GW2	05G WASH 138/69 kV transformer	Replace the George Washington 138/69 kV TR #2.	N/A	Same as 2b
						$3,099,500

Table 3b

#	BUS_NO	BUS	BREAKER	Network Upgrade Number	Cost
1	1045	05NATRIU 138.kV	I	n4204	$800,000
2	1045	05NATRIU 138.kV	K	n4204	$800,000
					$1,600,000

Table 4b - Breakers

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.

Potential Congestion due to Local Energy Deliverability

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.

Note: Only the most severely overloaded conditions are listed below. 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 shall study all overload conditions associated with the overloaded element(s) identified.

None.

Conclusion

Based upon the results of this System Impact Study, the construction of the Moundsville Power (PJM Project #Y3-068) natural gas generation project will require additional interconnection charges.

The cost for connecting to the George Washington 138kV Station:

- **Estimated station work cost: $1,569,700**
- **Estimated protection and relaying cost: $121,340**
- **Estimated local/network upgrade cost: $16,113,100**

Total estimated cost for project Y3-068: $17,804,140

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.

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 4

(AEP - AP) The 05TILTON-WINDSOR 138 kV line (from bus 243131 to bus 235428 ckt 1) loads from 94.35% to 102.66% (AC power flow) of its emergency rating (284 MVA) for the tower line contingency outage of '4743'. This project contributes approximately 27.78 MW to the thermal violation.

CONTINGENCY '4743'
OPEN BRANCH FROM BUS 242946 TO BUS 253965 CKT 1 / 242946 05TIDD 345 253965 15COLLIE 345 1
OPEN BRANCH FROM BUS 242946 TO BUS 235707 CKT 1 / 242946 05TIDD 345 235707 WYLIE RIDGE 345 1
END

Bus Number	Bus Name	Full Contribution
LTF	Y2-068	31.15
915481	Y3-068 OP1	27.78

Appendix 5

(AEP - AP) The 05TILTON-WINDSOR 138 kV line (from bus 243131 to bus 235428 ckt 1) loads from 94.35% to 102.66% (AC power flow) of its emergency rating (284 MVA) for the line fault with failed breaker contingency outage of '4743_C2'. This project contributes approximately 27.78 MW to the thermal violation.

CONTINGENCY '4743_C2'
OPEN BRANCH FROM BUS 242946 TO BUS 253965 CKT 1 / 242946 05TIDD 345 253965 15COLLIE 345 1
OPEN BRANCH FROM BUS 242946 TO BUS 235707 CKT 1 / 242946 05TIDD 345 235707 WYLIE RIDGE 345 1
END

Bus Number	Bus Name	Full Contribution
LTF	Y2-068	31.15
915481	Y3-068 OP1	27.78

Appendix 6

(AEP - AEP) The 05G WASH 138/69 kV transformer (from bus 243012 to bus 245935 ckt 2) loads from 5.69% to 104.08% (AC power flow) of its emergency rating (175 MVA) for the single line contingency outage of 'ADD_GW_BUSTIE'. This project contributes approximately 170.71 MW to the thermal violation.

CONTINGENCY 'ADD_GW_BUSTIE'
OPEN BRANCH FROM BUS 915485 TO BUS 243012 CKT 1
END

Bus Number	Bus Name	Full Contribution
235344	HANNIBAL	0.04
915481	Y3-068 OP1	170.71

Appendix 7

(AEP - AEP) The 05G WASH 138/69 kV transformer (from bus 243012 to bus 245935 ckt 2) loads from 23.58% to 104.37% (AC power flow) of its emergency rating (175 MVA) for the bus fault outage of 'ADD_GW2'. This project contributes approximately 142.71 MW to the thermal violation.

CONTINGENCY 'ADD_GW2'
DISCONNECT BUS 915485
END

Bus Number	Bus Name	Full Contribution
915481	Y3-068 OP1	142.71

Appendix 9

(AEP - AEP) The DILLES-SHADYSID 69 kV line (from bus 245086 to bus 245098 ckt 1) loads from 33.49% to 112.06% (AC power flow) of its emergency rating (46 MVA) for the single line contingency outage of '5213_B2_TOR773'. This project contributes approximately 37.71 MW to the thermal violation.

CONTINGENCY '5213_B2_TOR773'
OPEN BRANCH FROM BUS 915485 TO BUS 243026 CKT 1 / 243012 05G WASH 138 243026 05KAMMR1 138 1
END

Bus Number	Bus Name	Full Contribution
915481	Y3-068 OP1	37.71

Appendix 10

(AEP - AEP) The GLENDALE-BRUES 69 kV line (from bus 245937 to bus 245920 ckt 1) loads from 24.35% to 115.73% (AC power flow) of its emergency rating (48 MVA) for the single line contingency outage of '5213_B2_TOR773'. This project contributes approximately 46.53 MW to the thermal violation.

CONTINGENCY '5213_B2_TOR773'
OPEN BRANCH FROM BUS 915485 TO BUS 243026 CKT 1 / 243012 05G WASH 138 243026 05KAMMR1 138 1
END

Bus Number	Bus Name	Full Contribution
915481	Y3-068 OP1	46.53

Appendix 11 – Stability Report

Executive Summary

Generator Interconnection Request Y3-068 is for the addition of a 525 MW Maximum Facility Output (MFO) natural gas fueled facility to the AEP system with a Point of Interconnection (POI) at the George Washington 138 kV substation in Marshall County, West Virginia.

Y3-068 is now at the system impact study phase of PJM's Generation and Transmission Interconnection Process. This report describes a dynamic simulation analysis of Y3-068 as part of the overall system impact study.

The load flow scenario for the analysis was the 2017 light load case which was modified to include applicable queue projects. Y3-068 was dispatched at maximum power output and leading power factor.

Y3-068 was tested for compliance with NERC, PJM and other applicable criteria. 87 contingencies were 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) Three phase faults with loss of multiple-circuit tower line
d) Single phase faults with single phase stuck breaker
e) Single phase faults with delayed clearing at remote end due to primary relaying failure

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.

The results indicate that for the 87 fault contingencies tested on the 2017 light load case:

a) Y3-068 was able to ride through the faults (except for faults where protective action tripped Y3-068),
b) the system with Y3-068 included was found to be transiently stable,
c) voltages at the POI and nearby buses returned to an acceptable range for all contingencies, with system stability being maintained.

No mitigation were found to be required.

1. Introduction

Generator Interconnection Request Y3-068 is for the addition of a 525 MW Maximum Facility Output (MFO) natural gas fueled facility to the AEP system with a Point of Interconnection (POI) at the George Washington 138 kV substation in Marshall County, West Virginia.

As the Regional Transmission Operator, PJM Interconnection is responsible for planning the incorporation of generators into the grid. Y3-068 is now at the system impact study phase of PJM's Generation and Transmission Interconnection Process.

PJM contracted Power Systems Consultants (PSC) to carry out this dynamic simulation analysis of Y3-068 as part of the overall system impact study. This analysis is effectively a screening study to determine whether the addition of Y3-068 will meet the dynamics requirements of the NERC and PJM reliability standards.

In this report the Y3-068 project and how it is proposed to be connected to the grid is 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

Y3-068 consists two gas turbine generators and a steam turbine generator. The Y3-068 gas turbine generators are each rated at 170.3 MW (maximum winter rating) and the steam turbine generator is rated at 198.3 MW. Y3-068 machines are connected to the George Washington 138 kV substation (POI) via two 165 MVA 145 / 18 kV and one 220 MVA 142 / 18 kV generator step up (GSU) transformers and a 0.5 mile transmission line. The dynamic models for the Y3-068 plant are based on standard PSS/E models, with parameters supplied to PJM by the Developer.

Figure 1 shows the simplified one-line diagram of the Y3-068 loadflow model. Table 1 and 2 list the parameters given in the impact study data and the corresponding parameters of the Y3-068 loadflow model.

Additional project details are provided in Attachments 1 through 5:

- Attachment 1 contains the Impact Study Data which details the proposed Y3-068 project.
- Attachment 2 shows the one line diagram of the AEP network in the vicinity of Y3-068.
- Attachment 3 provides a diagram of the PSS/E model in the vicinity of Y3-068.
- Attachment 4 gives the Y3-068 PSS/E loadflow model.
- Attachment 5 details the dynamic model of the Y3-068 plant.

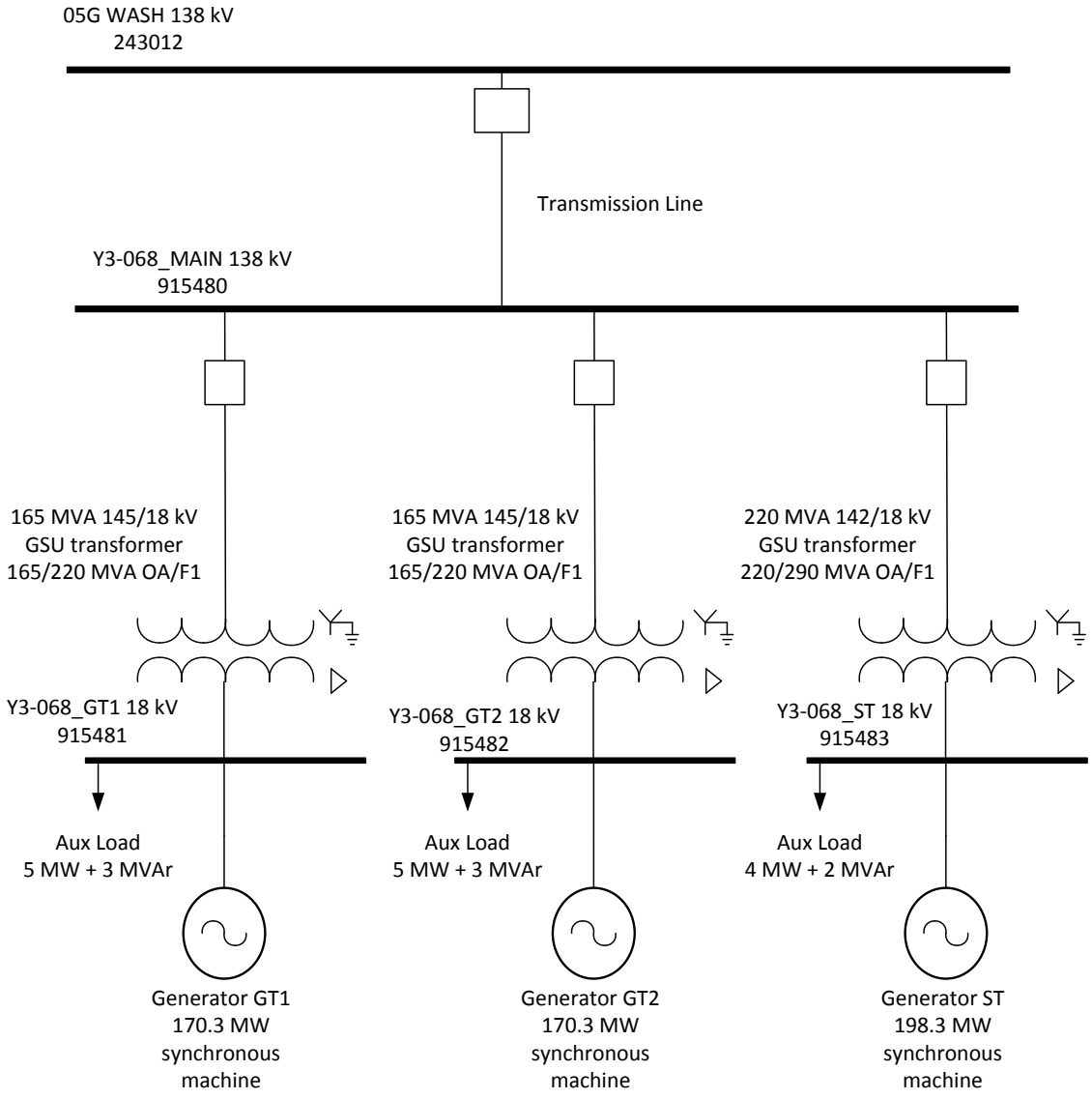

Figure 1: Y3-068 Plant Model

Table 1: Y3-068 GT Plant Model

	Impact Study Data	Model
Generators,	2 x 170.3 MW GT generators MVA base = 216 MVA Vt = 18 kV Unsaturated sub-transient reactance = j0.18 pu @ MVA base	2 x 170.3 MW generators Pgen 170.3 MW Pmax 170.3 MW Pmin 0 MW Qgen -18.6 MVAr Qmax 108 MVAr Qmin -80 MVAr Mbase 216 MVA Zsource j0.18 pu @ Mbase
GSU transformer	2 x 145/18 kV (WYEgnd/Delta) Rating = 165/220 MVA (OA/F1) Transformer base = 220 MVA Impedance 0.0024 + j0.12 @ 220 MVA Number of taps = 5 Tap step size = 2.5 %	2 x 145/18 kV Rating = 165/220 MVA (OA/F1) Transformer base = 220 MVA Impedance 0.0024 + j0.12 @ 220 MVA Number of taps = 5 Tap step size = 2.5 %
Auxiliary demand	2 X 5 MW + 3 MVAr	2 X 5 MW + 3 MVAr
Station load	2 X 2 MW + 1 MVAr	Not modeled

Transmission line	Length, 0.5 miles Impedances Per Mile @ 100 MVA base Z = 0.00019 + j0.00248 B = 0.00170	Impedances @ 100 MVA base Z = 0.000095 + j0.00124 B = 0.00085

Table 2: Y3-068 ST Plant Model

	Impact Study Data	Model
Generators,	1 x 198.3 MW ST Generator MVA base = 248 MVA Vt = 18 kV Unsaturated sub-transient reactance = j0.165 pu @ MVA base	1 x 198.3 MW ST Generator Pgen 198.3 MW Pmax 198.3 MW Pmin 0 MW Qgen -52.7 MVAr Qmax 135 MVAr Qmin -105 MVAr Mbase 248 MVA Zsource Mbase j0.165 pu @
GSU transformer	142/18 kV (WYEgnd/Delta) Rating = 220/290 MVA (OA/F1) Transformer base = 220 MVA Impedance 0.0024 + j0.12 @ 220 MVA Number of taps = 5 Tap step size = 2.5 %	142/18 kV Rating = 220/290 MVA (OA/F1) Transformer base = 220 MVA Impedance 0.0024 + j0.12 @ 220 MVA Number of taps = 5 Tap step size = 2.5 %
Auxiliary demand	4 MW + 2 MVAr	4 MW + 2 MVAr
Station load	1 MW + 0.5 MVAr	Not modeled

Transmission line	Length, 0.5 miles Impedances Per Mile @ 100 MVA base Z = 0.00019 + j0.00248 B = 0.00170	Included in Table 1 data

The maximum gross output is 538.9 MW ((2 x 170.3 MW) + 198.3 MW), with Maximum Facility Output ~525 MW accounting for the station auxiliary demand of 14 MW.

3. Loadflow and Dynamics Case Setup

The dynamics simulation analysis was carried out using PSS/E Version 32.2.1.

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

The selected load flow scenario is the 2017 light load case (which was derived from case employed for the X3-028 dynamic evaluation), with the following modifications:

a) Addition of all applicable queue projects prior to Y3-068.
b) Addition of Y3-068 queue project.
c) Removal of withdrawn and subsequent queue projects in the vicinity of Y3-068.
d) Dispatch of units in the PJM system in order to maintain slack generators within limits.
e) Removal of several distant generation units from the dynamic simulation to avoid initialization problems.

In the load flow the Y3-068 generators are set to maximum power output, 0.95 pu terminal voltage, and leading power factor.

Generation within the PJM500 system (area 225 in the PSS/E case) and within a 6-bus radius of Y3-068 has been dispatched online at maximum output (PMAX) – exceptions and the reasons for them are listed in Table 2.

Table 2: Generation at reduced output within 6-bus radius of Y3-068

Bus	Name	Unit	PGEN (MW)	PMAX (MW)	Reason
270000	20FOOTHL 345.00	1	170	191	Conflict with governor model, PMAX not achievable
270000	20FOOTHL 345.00	2	170	191	
270001	20ZELDA 345.00	1	170	191	Conflict with governor model, PMAX not achievable
270001	20ZELDA 345.00	2	170	191	

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

Bus	Name	Unit	PGEN (MW)	PMAX (MW)	Reason
270001	20ZELDA 345.00	3	170	191	
242940	05MUSKNG 345.00	5	585	600	Conflict with governor model, PMAX not achievable
242894	05MTG1 26.000	1H	557.45	673.2	Conflict with governor model, PMAX not achievable
242894	05MTG1 26.000	1R	554.8	646.8	

4. Fault Cases

Table 3 to Table 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 POI or one bus removed[2] (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) Three phase faults with loss of multiple-circuit tower line
d) Single phase faults with single phase stuck breaker
e) Single phase 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 Y3-068 have not withdrawn from the PJM queue, and are not greater than the queue position under study.

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

5. Evaluation Criteria

This study is focused on Y3-068, 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 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 Y3-068 generators should maintain their pre-contingent power output following the fault.

6. Summary of Results

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

The results indicate that for the 87 fault contingencies tested on the 2017 light load case:

a) Y3-068 was able to ride through the faults (except for faults where protective action tripped Y3-068),
b) the system with Y3-068 included was found to be transiently stable,
c) voltages at the POI and nearby buses returned to an acceptable range for all contingencies, with system stability being maintained.

No mitigation were found to be required.

Table 3: Steady State Operation

Fault ID	Duration	Y3-068 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)	Result
3N.01	Fault at George Washington 138 kV POI on Y3-068 circuit (trips Y3-068 units).	4.5 / 4.5	Stable (Trips Y3-068 units)
3N.02	Fault at George Washington 138 kV POI on George Washington 138/69 kV transformer (trips Y3-068 units).	4.5 / 4.5	Stable (Trips Y3-068 units)
3N.03	Fault at George Washington 138 kV POI on Kammer circuit.	4.5 / 4.5	Stable
3N.04	Fault at George Washington 138 kV POI on Natrium circuit.	4.5 / 4.5	Stable
3N.05	Fault at George Washington 138 kV POI on Big Grave Creek - Valley Grove - West Liberty - Tidd circuit.	4.5 / 4.5	Stable
3N.06	Fault at George Washington 69 kV on George Washington 138/69 kV transformer (trips Y3-068 units).	4.5 / 4.5	Stable (Trips Y3-068 units)
3N.07	Fault at George Washington 69 kV on Moundsville circuit 1.	4.5 / 4.5	Stable
3N.08	Fault at George Washington 69 kV on Ireland - Kammer circuit.	4.5 / 4.5	Stable
3N.09	Fault at George Washington 69 kV on Dilles Bottom - West Shadyside - West Monroe Street - West Bellaire circuit.	4.5 / 4.5	Stable
3N.10	Fault at Kammer 138 kV on George Washington circuit.	4.5 / 4.5	Stable
3N.11	Fault at Kammer 138 kV on Brues - Bethleham - County Line - Big Grave Creek - Fort Henry - Tidd 138 kV circuit.	4.5 / 4.5	Stable
3N.12	Fault at Kammer 138 kV on West Bellaire circuit.	4.5 / 4.5	Stable
3N.13	Fault at Kammer 138 kV on Natrium circuit.	4.5 / 4.5	Stable
3N.14	Fault at Kammer 138 kV on Transformer T1 (trips Kammer units 1A and 1B).	4.5 / 4.5	Stable (Trips Kammer units 1A and 1B)
3N.15	Fault at Kammer 138 kV on Transformer T2 (trips Kammer units 2A and 2B).	4.5 / 4.5	Stable (Trips Kammer units 2A and 2B)
3N.16	Fault at Kammer 138 kV on Transformer T3 (trips Kammer units 3A and 3B).	4.5 / 4.5	Stable (Trips Kammer units 3A and 3B)
3N.17	Fault at Kammer 138 kV on Kammer 138/69 kV transformer.	4.5 / 4.5	Stable

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
3N.18	Fault at Kammer 138 kV on Kammer 345/138 kV transformer T3.	4.5 / 4.5	Stable
3N.19	Fault at Natrium 138 kV on George Washington circuit.	4.5 / 4.5	Stable
3N.20	Fault at Natrium 138 kV on Kammer circuit.	4.5 / 4.5	Stable
3N.21	Fault at Natrium 138 kV on Switzer - Summerfield circuit.	4.5 / 4.5	Stable
3N.22	Fault at Natrium 138 kV on Ball Hollow - Caldwell - Muskingum River Plant circuit.	4.5 / 4.5	Stable
3N.23	Fault at Natrium 138 kV on Natrium 138 / 69 kV transformer T1.	4.5 / 4.5	Stable
3N.24	Fault at Tidd 138 kV on Big Grave Creek - Valley Grove - West Liberty - George Washington circuit.	4.5 / 4.5	Stable
3N.25	Fault at Tidd 138 kV on South Cadiz - Carrollton - Sunnyside circuit.	4.5 / 4.5	Stable
3N.26	Fault at Tidd 138 kV on Brues - Bethleham - County Line - Fort Henry - Kammer circuit.	4.5 / 4.5	Stable
3N.27	Fault at Tidd 138 kV on Broadacre - East Amsterdam - Malvern - Wagenhals circuit.	4.5 / 4.5	Stable
3N.28	Fault at Tidd 138 kV on Steubenville circuit.	4.5 / 4.5	Stable
3N.29	Fault at Tidd 138 kV on Carnegie - Weirton 1 circuit.	4.5 / 4.5	Stable
3N.30	Fault at Tidd 138 kV on Mahans - Weirton 2 circuit.	4.5 / 4.5	Stable
3N.31	Fault at Tidd 138 kV on Tidd 138/69 kV transformer TR12.	4.5 / 4.5	Stable
3N.32	Fault at Tidd 138 kV on Tidd Gen 1 transformer (trips Tidd unit 1).	4.5 / 4.5	Stable (Trips Tidd unit 1)
3N.33	Fault at Tidd 138 kV on Tidd 345 / 138 kV transformer TC.	4.5 / 4.5	Stable

Table 5: Three-phase Faults With Loss Of Multiple-Circuit Tower Line

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
3T.01	Fault at Kammer 345 kV on Muskingum River Plant circuit resulting in tower failure. Fault cleared with loss of Kammer - Muskingum River Plant and Muskingum River Plant - Beverly circuits. CONTINGENCY '473'	4.5 / 4.5	Stable
3T.02	Fault at Tidd 345 kV on Beverly circuit resulting in tower failure. Fault cleared with loss of Tidd - Beverly, Tidd - West Bellaire and Kammer - West Bellaire circuits and West Bellaire Transformer T1. CONTINGENCY '476'	4.5 / 4.5	Stable
3T.03	Fault at Tidd 345 kV on Beverly circuit resulting in tower failure. Fault cleared with loss of Tidd - Beverly and Kammer - Muskingum River Plant circuits. CONTINGENCY '474'	4.5 / 4.5	Stable

Table 6: Single-phase Faults with Stuck Breaker

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
1B.01	Fault at George Washington 138 kV POI on Y3-068 (trips Y3-068 units). Breaker stuck to Kammer circuit. Fault cleared with loss of George Washington 138 / 69 kV transformer and Kammer circuit.	4.5 / 17	Stable (Trips Y3-068 units)
1B.02	Fault at George Washington 138 kV POI on George Washington 138 / 69 kV Transformer (trips Y3-068 units). Breaker J stuck. Fault cleared with loss of Natrium and Big Grave Creek - Valley Grove - West Liberty - Tidd circuits.	4.5 / 17	Stable (Trips Y3-068 units)
1B.03	Fault at George Washington 138 kV POI on Kammer circuit. Breaker I stuck. Fault cleared with loss of George Washington 138 / 69 kV transformer and Y3-068 units.	4.5 / 17	Stable (Trips Y3-068 units)
1B.04	Fault at George Washington 138 kV POI on Natrium circuit. Breaker B stuck. Fault cleared with loss of Big Grave Creek - Valley Grove - West Liberty - Tidd circuit.	4.5 / 17	Stable
1B.05	Fault at George Washington 138 kV POI on Big Grave Creek - Valley Grove - West Liberty - Tidd circuit. Breaker A stuck. Fault cleared with loss of Natrium circuit.	4.5 / 17	Stable
1B.06	Fault at George Washington 69 kV on Moundsville circuit 1. Breaker D stuck. Fault cleared with loss of George Washington 138/69 kV transformer, Y3-068 units, George Washington - Kammer 138 kV, Ireland - Kammer 69 kV, Moundsville 2 and Dilles Bottom - West Shadyside - West Monroe Street - West Bellaire circuits.	4.5 / 17	Stable (Trips Y3-068 units)
1B.07	Fault at Kammer 138 kV on George Washington circuit. Breaker T stuck. Fault cleared with loss of Kammer units 3A and 3B	4.5 / 17	Stable (Trips Kammer units 3A and 3B)
1B.08	Fault at Kammer 138 kV on Brues - Bethleham - County Line - Big Grave Creek - Fort Henry - Tidd circuit. Breaker N stuck. Fault cleared with loss of Ormet No. 4 circuit.	4.5 / 17	Stable
1B.09	Fault at Kammer 138 kV on West Bellaire circuit. Breaker P stuck. Fault cleared with loss of FGD 1 circuit.	4.5 / 17	Stable
1B.10	Fault at Kammer 138 kV on Natrium circuit. Breaker V stuck. Fault cleared with no additional circuits lost.	4.5 / 17	Stable
1B.11	Fault at Kammer 138 kV on Transformer T1 (trips Kammer units 1A and 1B). Breaker H stuck. Fault cleared with loss of Ormet No. 2 circuit.	4.5 / 17	Stable (Trips Kammer units 1A and 1B)

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
1B.12	Fault at Kammer 138 kV on Transformer T2 (trips Kammer units 2A and 2B). Breaker K stuck. Fault cleared with loss of Ormet No. 3 circuit.	4.5 / 17	Stable (Trips Kammer units 2A and 2B)
1B.13	Fault at Kammer 138 kV on Transformer T3 (trips Kammer units 3A and 3B). Breaker T stuck. Fault cleared with loss of George Washington circuit.	4.5 / 17	Stable (Trips Kammer units 3A and 3B)
1B.14	Fault at Kammer 138 kV on Kammer 138/69 kV transformer. Breaker U stuck. Fault cleared with loss of Kammer units 3A and 3B.	4.5 / 17	Stable (Trips Kammer units 3A and 3B)
1B.15	Fault at Kammer 138 kV on Kammer 345/138 kV transformer T3. Breaker B stuck. Fault cleared with loss of FDG 2 circuit.	4.5 / 17	Stable
1B.16	Fault at Natrium 138 kV on George Washington circuit. Breaker H stuck. Fault cleared with loss of Switzer - Summerfield circuit.	4.5 / 17	Stable
1B.17	Fault at Natrium 138 kV on Kammer circuit. Breaker M stuck. Fault cleared with loss of Ball Hollow - Caldwell - Muskingum River Plant circuit.	4.5 / 17	Stable
1B.18	Fault at Natrium 138 kV on Switzer - Summerfield circuit. Breaker I stuck. Fault cleared with loss of George Washington circuit.	4.5 / 17	Stable
1B.19	Fault at Natrium 138 kV on Ball Hollow - Caldwell - Muskingum River Plant circuit. Breaker G stuck. Fault cleared with loss of Kammer circuit.	4.5 / 17	Stable
1B.20	Fault at Tidd 138 kV on Big Grave Creek - Valley Grove - West Liberty - George Washington circuit. Breaker C stuck. Fault cleared with loss of Mahans - Weirton 2 circuit.	4.5 / 17	Stable
1B.21	Fault at Tidd 138 kV on Brues - Bethleham - County Line - Fort Henry - Kammer circuit. Breaker B stuck. Fault cleared with loss of Wheeling Steel No. 1 circuit.	4.5 / 17	Stable
1B.22	Not Used	N/A	N/A
1B.23	Fault at Tidd 138 kV on Carnegie - Weirton 1 circuit. Breaker D stuck. Fault cleared with loss of Wheeling Steel No. 2 circuit.	4.5 / 17	Stable
1B.24	Fault at Tidd 138 kV on Mahans - Weirton 2 circuit. Breaker C stuck. Fault cleared with loss of George Washington - Big Grave Creek – Brues - Valley Grove - West Liberty circuit.	4.5 / 17	Stable
1B.25	Fault at Tidd 138 kV on Tidd Gen 1 transformer (trips Tidd unit 1). Breaker K stuck. Fault cleared with loss of Tidd 345 / 138 kV transformer 1.	4.5 / 17	Stable (Trips Tidd unit 1)

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
1B.26	Fault at Tidd 138 kV on Tidd 345 / 138 kV transformer TC. Breaker K stuck. Fault cleared with loss of Tidd Gen 1 transformer (trips Tidd unit 1).	4.5 / 17	Stable (Trips Tidd unit 1)

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

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
1D.01	Fault at George Washington 138 kV POI on Big Grave Creek - Valley Grove - West Liberty - Tidd circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.02	Not Used	N/A	N/A
1D.03	Fault at George Washington 138 kV POI on Kammer circuit. Delayed clearing at Kammer.	4.5 / 60	Stable
1D.04	Fault at George Washington 138 kV POI on Natrium circuit. Delayed clearing at Natrium.	4.5 / 60	Stable
1D.05	Fault at George Washington 69 kV on George Washington 138/69 kV transformer (trips Y3-068 units). Delayed clearing at George Washington Y3-068 circuit.	4.5 / 60	Stable (Trips Y3-068 units)
1D.06	Fault at Moundsville 69 kV on George Washington circuit 1. Delayed clearing at George Washington.	4.5 / 60	Stable
1D.07	Fault at Kammer 69 kV on Ireland - George Washington circuit. Delayed clearing at George Washington.	4.5 / 60	Stable
1D.08	Fault at West Bellaire 69 kV on Dilles Bottom - West Shadyside - West Monroe Street - George Washington circuit. Delayed clearing at George Washington.	4.5 / 60	Stable
1D.09	Fault at Kammer 138 kV on George Washington circuit. Delayed clearing at George Washington.	4.5 / 60	Stable
1D.10	Fault at Kammer 138 kV on Brues - Bethleham - County Line - Big Grave Creek - Fort Henry - Tidd circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.11	Not Used	N/A	N/A
1D.12	Fault at Kammer 138 kV on Natrium circuit. Delayed clearing at Natrium.	4.5 / 60	Stable
1D.13	Fault at Kammer 345 kV on Kammer 345 / 138 kV transformer T3. Delayed clearing at Kammer 138 kV.	4.5 / 60	Stable
1D.14	Fault at West Bellaire 138 kV on Kammer circuit. Delayed clearing at Kammer.	4.5 / 60	Stable
1D.15	Fault at Natrium 138 kV on Kammer circuit. Delayed clearing at Kammer.	4.5 / 60	Stable
1D.16	Fault at Natrium 138 kV on George Washington circuit. Delayed clearing at George Washington.	4.5 / 60	Stable
1D.17	Fault at Summerfield 138 kV on Switzer - Natrium circuit. Delayed	4.5 / 60	Stable

Fault ID	Fault description	Clearing Time Near & Remote (Cycles)	Result
	clearing at Natrium.		
1D.18	Fault at Muskingum River Plant 138 kV on Ball Hollow - Caldwell - Natrium circuit. Delayed clearing at Natrium.	4.5 / 60	Stable
1D.19	Fault at Tidd 138 kV on Big Grave Creek - Valley Grove - West Liberty - George Washington circuit. Delayed clearing at George Washington.	4.5 / 60	Stable
1D.20	Fault at Tidd 138 kV on Brues - Bethleham - County Line - Fort Henry - Kammer circuit. Delayed clearing at Kammer circuit.	4.5 / 60	Stable
1D.21	Not Used	N/A	N/A
1D.22	Fault at Sunnyside 138 kV on South Cadiz - Carrollton - Tidd circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.23	Fault at Wagenhals 138 kV on Broadacre - East Amsterdam - Malvern - Tidd circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.24	Fault at Steubenville 138 kV on Tidd circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.25	Fault at Weirton 1 138 kV on Carnegie - Tidd circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.26	Fault at Tidd 345 kV on Tidd 345 / 138 kV transformer TC. Delayed clearing at Tidd 138 kV.	4.5 / 60	Stable
1D.27	Fault at Brues 138 kV on Kammer - Big Grave Creek - Bethleham - County Line - Fort Henry - Tidd 138 kV circuit. Delayed clearing at Tidd.	4.5 / 60	Stable
1D.28	Fault at Brues 138 kV on Kammer - Big Grave Creek - Bethleham - County Line - Fort Henry - Tidd 138 kV circuit. Delayed clearing at Kammer.	4.5 / 60	Stable