# *Second Revised*
# *Generation Interconnection*
# *System Impact Study Report*

## *For*

## *PJM Generation Interconnection Request*
## *Queue Position AA1-111*

## *"Moshannon-East Towanda 230 kV"*

*Second Revised: April 2021*

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# 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

Renovo Energy Center, LLC the Interconnection Customer (IC), has proposed a natural gas generating facility located in Clinton County, PA. The installed facilities will have a total capability of 463 MW with 463 MW of this output being recognized by PJM as capacity. The customer requests backfeed from the Transmission Owner by June 2023. The proposed Commercial Operation Date for this project is June 2024[1]. This study does not imply a Mid-Atlantic Interstate Transmission (MAIT) commitment to this in-service date.

# Revisions since February 2021 System Impact Study Report

The AA1-111 System Impact Study results were updated based on the original load forecast provided with the AA2/AB1 RTEP study. The original AA1-111 study results were based on a revised load forecast which is inconsistent with PJM's current study process for maintaining core assumptions provided with each RTEP study. With the updated analysis, it was determined that with the exception of the stability issue, no overloads were identified for load flow.

See the Network Impacts section of this report for the updated analysis results. The physical interconnection costs have not been updated. The updated interconnection work scope and cost estimates will be provided in the Facilities Study Report.

[1] The AA1-111 Commercial Operation Date will be updated in the Facilities Study to follow.

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## Point of Interconnection

AA1-111 will interconnect with the Penelec transmission system along the Moshannon-East Towanda 230kV line.

## Cost Summary[2]

The AA1-111 project will be responsible for the following costs:

| Description | Cost |
|---|---|
| Attachment Facilities | $ 0 |
| Direct Connection Network Upgrades | $ 8,804,900 |
| Non Direct Connection Network Upgrades | $ 192,200 |
| Allocation for New System Upgrades | $ 12,572,600 |
| Contribution for Previously Identified Upgrades | $ 0 |
| **Total Costs** | **$ 21,569,700** |

## Attachment Facilities

There are no Attachment Facilities are required to support this interconnection.

## Direct Connection Cost Estimate

The total preliminary cost estimate for the Direct Connection work is given in the table below. These costs do not include CIAC Tax Gross-up.

| Description | Activity Cost |
|---|---|
| AA1-111 Interconnection SS. New 230kV three breaker ring bus substation. (n4956) | $ 8,189,500 |
| Marshall-Moshannon 230kV, Loop to Proposed 3-Breaker Ring Bus. Install a loop, approx. 200' in length, by removing an h-frame structure and installing two new 3-way deadend structures. (n4957) | $ 615,400 |
| **Total Direct Connection Facility Costs** | **$ 8,804,900** |

[2] Note that the costs will be updated in the Facilities Study Report.

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## Non-Direct Connection Cost Estimate

The total preliminary cost estimate for the Non-Direct Connection work is given in the table below. These costs do not include CIAC Tax Gross-up.

| Description | Activity Cost |
|---|---|
| AA1-144 Interconnect SS. Revise anti-islanding scheme for AA1-111 Interconnect line. (n4967) | $ 89,700 |
| Marshall SS. Revise anti-islanding scheme for AA1-111 Interconnect line. (n4958) | $ 89,500 |
| Moshannon 230 kV SS. Adjust Remote Relay Settings at Moshannon 230 kV substation. (n4959) | $ 13,000 |
| **Total Non-Direct Connection Facility Costs** | **$ 192,200** |

## Transmission Owner Scope of Work

The interconnection of the Project will require direct connection upgrades consisting of a new 230 kV three breaker ring bus interconnection switching station and a one span loop of the Marshall - Moshannon 230 kV line. The new switching station will be adjacent to Chapman substation. The IC will be responsible for acquiring all easements, properties and permits that may be required to construct both the new interconnection switching station and the associated attachment facilities. The IC will also be responsible for the rough grade of the property and an access road to the proposed three breaker ring bus site. The project will also require non-direct connection upgrades at the remote end substations. A summary of the Project connection facilities that will be required for the Project are shown in Attachment 2.

## Schedule

Based on the scope of the direct connection for the Primary POI, it is expected to take a minimum of 20 months from the signing of an Interconnection Connection Service Agreement to complete the installation required for the Project. This includes a preliminary payment that compensates FE for the first three months of the engineering design work that is related to the construction of the AA1-111 230 kV interconnection substation. It also assumes that the IC will provide the property for the AA1-111 230 kV interconnection substation and all right-of-way, permits, easements, etc. that will be needed. A further assumption is that there will be no environmental issues with any of the new properties associated with this project, that there will be no delays in acquiring the necessary permits for implementing the defined direct connection and network upgrades, and that PJM will allow all transmission system outages when requested.

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## Interconnection Customer Requirements

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.

3. The Interconnection Customer seeking to interconnect a wind generation facility shall maintain meteorological data facilities as well as provide that meteorological data which is required per item 5.iv. of Schedule H to the Interconnection Service Agreement.

4. The purchase and installation of a fully rated circuit breaker on the high side of the AA1-111 230-23 kV step-up transformer.

5. The purchase and installation of the minimum required FE generation interconnection relaying and control facilities. This includes over/under voltage protection, over/under frequency protection, and zero sequence voltage protection relays.

6. The purchase and installation of a 230 kV interconnection metering instrument transformer. FE will provide the ratio and accuracy specifications based on the customer load and generation levels.

7. The purchase and installation of a revenue class meter for each unit to measure the power delivered in compliance with the FE standards.

8. The purchase and installation of supervisory control and data acquisition (SCADA) equipment to provide information in a compatible format to the FE Transmission System Control Center.

9. The establishment of dedicated communication circuits for SCADA report to the FE Transmission System Control Center.

10. A compliance with the FE and PJM generator power factor and voltage control requirements.

11. The execution of a back-up retail service agreement with Penelec to serve the customer load supplied from the IC's interconnection point.

12. The rough grade of the property for the AA1-111 230 kV interconnection substation and an access road for the delivery of equipment to this site.

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# 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.

## Penelec Requirements

The Interconnection Customer will be required to comply with all FE Revenue Metering Requirements for Generation Interconnection Customers. The Revenue Metering Requirements may be found within the "FirstEnergy Requirements for Transmission Connected Facilities" document located at the following links:

http://www.firstenergycorp.com/feconnect

http://www.pjm.com/planning/design-engineering/to-tech-standards.aspx

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# Network Impacts

The Queue Project AA2-000 (AA1-111) was evaluated as a 463.0 MW (Capacity 463.0 MW) injection as a tap of the Chapman to Lobo 230 kV line in the PenElec area. Project AA2-000 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AA2-000 was studied with a commercial probability of 100%. Potential network impacts were as follows:

**Study Assumptions:**

- The model used in this study includes the Stability reinforcement required by this project.

Potential network impacts were as follows:

## Summer Peak Analysis - 2019

**Generator Deliverability**

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

None

**Multiple Facility Contingency**

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

None

**Contribution to Previously Identified Overloads**

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

None

**Steady-State Voltage Requirements**

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

None

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**Stability and Reactive Power Requirement**

*(Results of the dynamic studies should be inserted here)*

Due to stability issues identified with the original 230kV interconnection, a new 230-345kV interconnection option was studied. The cost of the stability reinforcement is provided in the New System Reinforcements section below and the Stability Study Results are included in Attachment 4.

**Short Circuit**

*(Summary of impacted circuit breakers)*

None

## Affected System Analysis & Mitigation

### NYISO Impacts:

NYISO performed a System Impact Study for Q654 considering the AA1-111 generation and found no additional upgrades to be needed.

**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

## Light Load Analysis - 2019

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

Not required.

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# Summer Peak Analysis Reinforcements

| ID | Idx | Facility | Upgrade Description | Cost | Cost Allocated to AA2-000 | Upgrade Number |
|---|---|---|---|---|---|---|
| 11 | N/A | Stability Reinforcement | **PENELEC**<br>Project Id: n5740<br>Description : Stability Reinforcement for AA1-111<br>• Install a 230-345kV transformer between the proposed AA1-111 interconnection switchyard and the NYSEG Q654 interconnection switchyard.<br>• At AA1-111 interconnection switchyard, install a 345 / 230 kV transformer, 230 kV breaker, and 345 kV breaker.<br>Cost : $12,572,600<br>Type : CON<br>Time Estimate : 28 Months | $12,572,600 | $12,572,600 | n5740 |
| | | | **TOTAL COST** | **$12,572,600** | **$12,572,600** | |

## Light Load Load Flow Analysis Reinforcements

**New System Reinforcements**

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

None

**Contribution to Previously Identified System Reinforcements**

*(Overloads initially caused by prior Queue positions with additional contribution to overloading by this project. This project may have a % allocation cost responsibility which will be calculated and reported for the Impact Study)*
*(Summary form of Cost allocation for transmission lines and transformers will be inserted here if any)*

None

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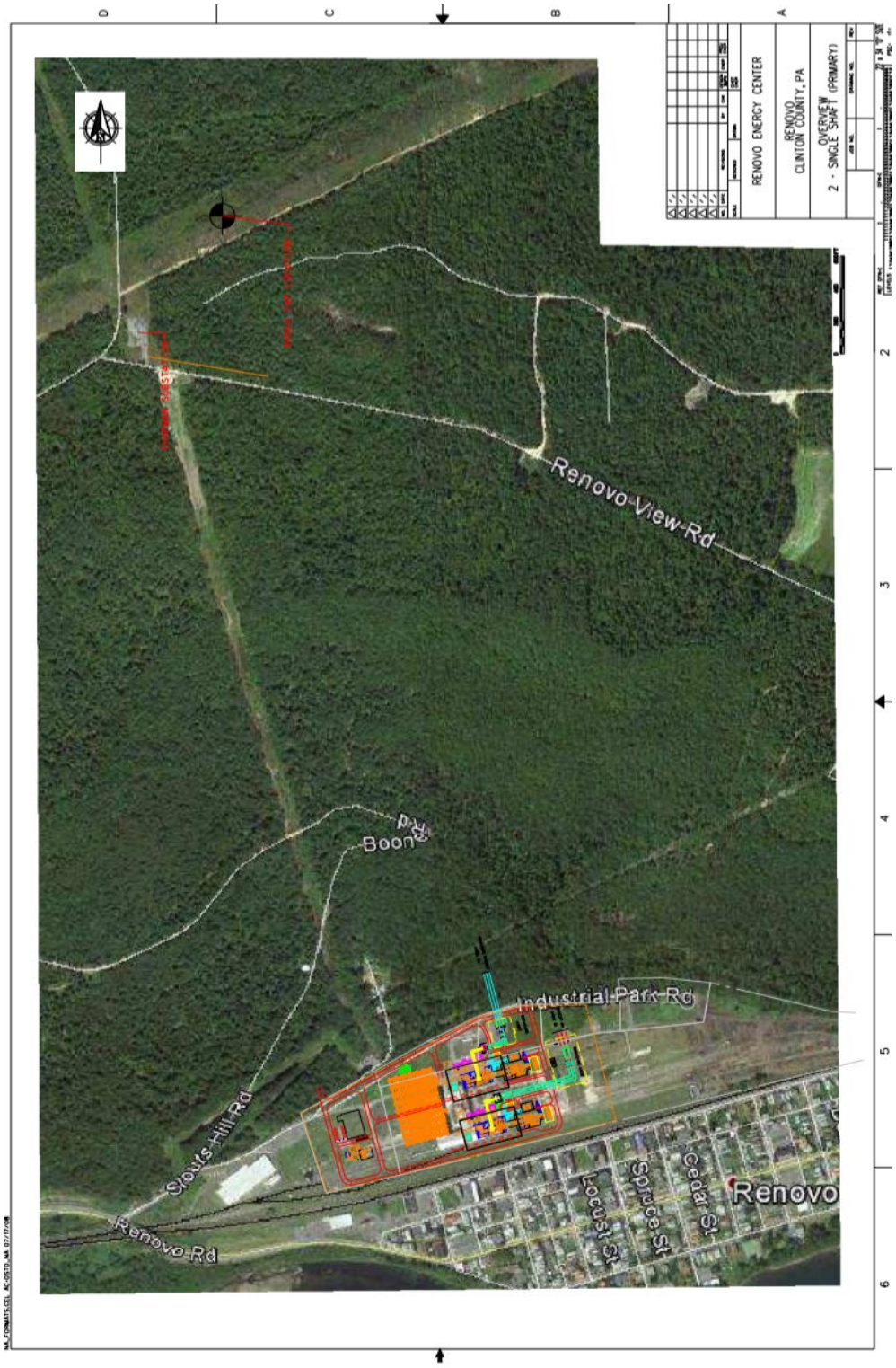
# Attachment 1

## Site Plan

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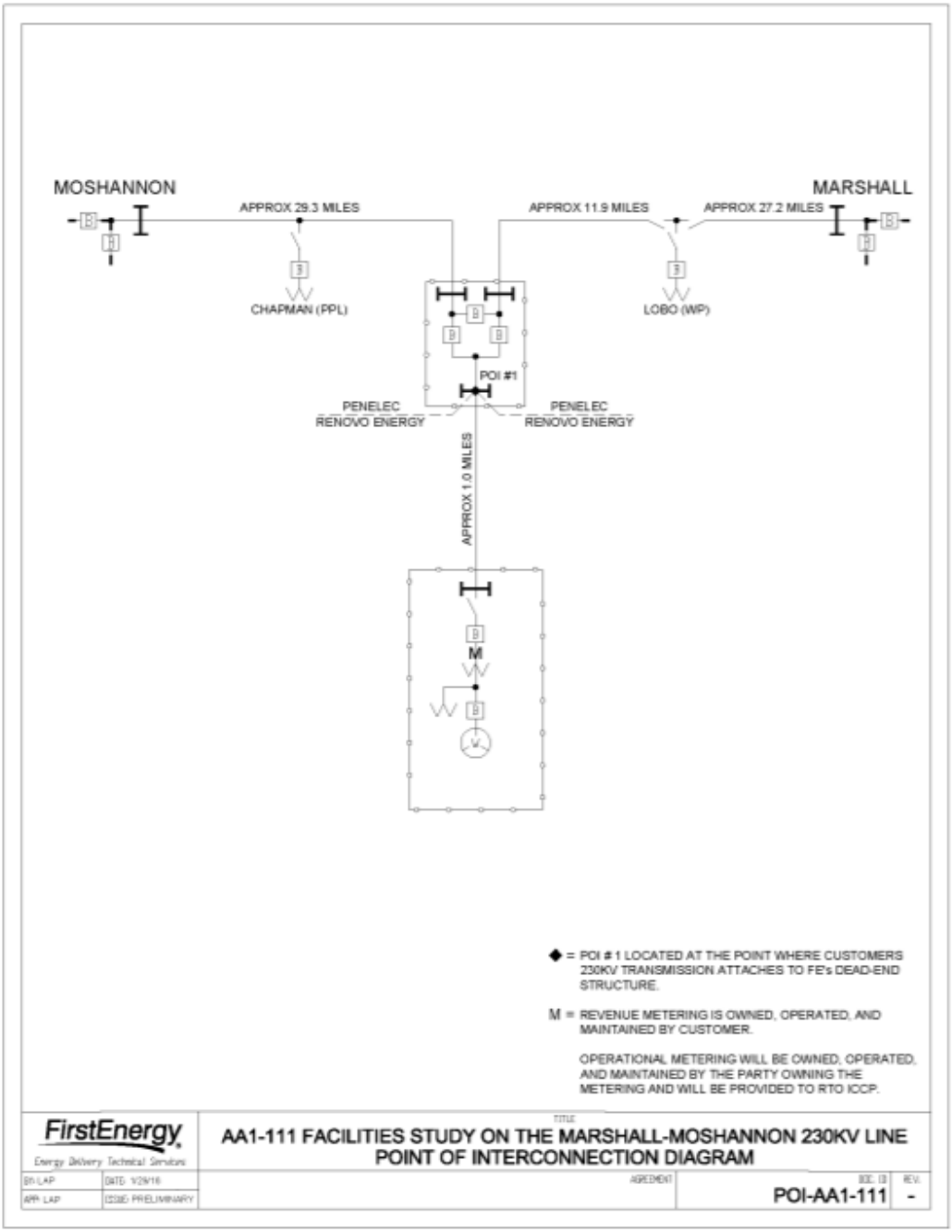
# Attachment 2

# One Line Diagram[3]




[3] Note this one line does not include the stability reinforcement. The one line in the Facilities Study will be updated to include the tie between the FE's 230 kV interconnection switchyard and NYSEG's 345 kV switchyard.

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# Attachment 3

## 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.

None

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# Attachment 4

# Stability Analysis

## Executive Summary

PJM Queue project AA2-000 is a request for 472.4 MW Maximum Facility Output natural gas generating facility. The AA2-000 Point of Interconnection (POI) is a new 230 kV station on Moshannon – East Towanda 230 kV transmission circuits in PENELEC transmission System, Clinton County, Pennsylvania.

This study is based on the RTEP 2019 light load case 2019_BaseCases_AA2_Phase2 and modified to include applicable queue projects. PJM queue project AA2-000 was dispatched at a maximum power transfer of 461.7 MW total and POI voltage of 235.0 kV (1.022 p.u.), consistent with the default generator reference voltage specified in PJM Manual 03 *Transmission Operations* Section 3.3.3 for generator connections to the PJM 230 kV system.

AA2-000 was tested for compliance with NERC, PJM and other applicable criteria. 70 contingencies were studied, each with a 15 second simulation time period.

Based on the contingencies tested, AA2-000 meets criteria for all contingencies tested.

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## Description

This study evaluates the stability and dynamics for PJM queue project AA2-000. The POI is a new 230 kV Station in the PENELEC area. The existing Moshannon – East Towanda 230 kV is tapped in/out to connect the new station to PENELEC 230 kV system. The AA2-000 project is comprised of one gas turbine generators. The gas turbine is modeled at 472.4 MW gross winter output of which 9.4 MW is being consumed as auxiliary and station service load. For this stability study, the AA2-000 project was studied as a total net injection of 461.7 MW into PENELEC 230 kV transmission system.

## Criteria

The stability study for AA2-000 was performed on a RTEP 2019_BaseCases_AA2_Phase2 light load-case for normal operating conditions, and modified to include applicable queue projects. The range of contingencies evaluated was limited to those necessary to assess compliance with NERC, PJM and other applicable criteria. Simulation time was 15 seconds for all faults.

Simulated NERC Standard TPL-001 faults include:

1. Three-phase (3ph) fault with normal clearing (Category P1)
2. Single-line-to-ground (slg) with normal clearing for bus faults (Category P2)
3. Single-line-to-ground (slg) with delayed clearing as a result of breaker failure (Category P4)
4. Single-line-to-ground (slg) with delayed clearing as a result of protection failure (Category P5)
5. Single-line-to-ground (slg) with normal clearing for common structure (Category P7)

Note: For generator interconnection studies, Category P3 and P6 faults will be studied on an as needed basis.

Other applicable criteria tested include:

1. Transmission Owner (TO) specific criteria
2. Based on the contingencies tested, AA2-017 meets criteria for all contingencies tested.

The system was tested for all lines in service condition and the faults listed above. Specific fault descriptions and breaker clearing times used for this study are provided in Appendix A.

All generators were monitored to assess transient stability and satisfactory post-contingency conditions.

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## Case Setup

Generators within 5 buses from the generator(s) under study are dispatched at their maximum power output and were set to hold scheduled voltages.

Studies were completed using RTEP 2019_BaseCases_AA2_Phase2 light load case including applicable queue projects.

Specific dispatch conditions at the generator terminals for the AA2-000 generators, as obtained in the power flow solution, are illustrated below:

| | GTG |
|---|---|
| Gross power output (MW) | 472.4 |
| Reactive power output (MVARS) | 20.5 |
| Auxiliary Load (MW/MVARS) | 9.4, 5.8 |
| Net real power injection (MW) @ 230 kV Bus | 461.7 |
| Voltage at the POI (P.U.) | 1.022 |

## Results

### Simulation Initialization

The case was initialized successfully. No errors were reported.

### 20 second no fault test (Steady State evaluation)

The system successfully met the 20 second run test without any significant deviations in system states.

### Simulation Results

Dynamics and stability was tested using Siemens/PTI PSS/E Version 32, the RTEP 2019_BaseCases_AA2_Phase2 case with a Light Load condition and the data supplied by the developer.

Transient Stability: For all cases studied for TPL 001-4_P1, TPL 001-4_P2, TPL 001-4_P4, and TPL 001-4_P5 transient stability is maintained, with all oscillations stabilized in less than 15 seconds. Also, the voltage levels returned to acceptable levels for all cases following the fault clearance. Hence, no transient stability issues were identified for above mentioned contingencies.

Small Signal (if applicable): N/A

SPS: N/A

Maintenance outage: No maintenance outage conditions were evaluated.

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## Conclusion

Transient stability is maintained for all contingencies tested.

### Mitigations:

The transmission system reinforcement provided by TO which adds a 230/345 kV transformer at the POI station was added. Figure B-1shows the connection detail. This reinforcement is to resolve instability caused by contingency 3ph fault at AA2_000 - Chapman - Moshannon 230 kV line.

### Recommendations:

1) **Installation of out-of-step protection is recommended**: This study was made using a certain set of operating conditions. There may be other operating conditions, although less probable, that can create stability problems. It is the Customer's responsibility to protect their own equipment from damage due to disturbances on the transmission system by installing out-of-step protection on their generators.

**Note**: While the stability analysis has been performed at extreme system conditions, there is a potential that evaluation at a different level of generator MW and/or MVAR output at different system load levels and operating conditions may disclose unforeseen stability problems. The regional reliability analysis routinely performed to test all system changes will include one such evaluation. Any problems uncovered in that or other operating or planning studies will need to be resolved.

Moreover, when the proposed generating station is designed and plant specific dynamic data for the plant and its controls are available, it must be forwarded to PJM. If it is different than the data provided for this study, a transient stability analysis at a variety of expected operating conditions using the more accurate data shall be performed to verify impact on the dynamic performance of the system. Note that any and all changes to the generation equipment's dynamic data, including the GSU data, must be submitted to PJM for evaluation.

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# Appendix A: Fault Table

| No. | Contingency ID | Type of Fault | Clearing time (cycles) | | Results |
|---|---|---|---|---|---|
| | | | Normal | Delayed | |
| **Criteria = TPL 001-4_P1** | | | | | |
| 01 | AA2-000-AA2-000-P1-01 | 3ph fault at AA2_000 - Chapman - Moshannon 230 kV | 5.0 | N/A | Stable |
| 02 | AA2-000-AA2-000-P1-02 | 3ph fault at AA2-000 - Lobo - Marshall/Laurel Hill 230 kV | 5.0 | N/A | Stable |
| 03 | AA2-000-MARS-P1-01 | 3ph fault at Marshall - Laurel Hill 230 kV, Loss of Gen | 5.0 | N/A | Stable |
| 04 | AA2-000-MARS-P1-02 | 3ph fault at Marshall - Grover - AA1-144 Tap 230 kV | 5.0 | N/A | Stable |
| 05 | AA2-000-AA1-144P1-01 | 3ph fault at AA1-144 POI - AA1-144 Main 230 kV, Loss of Gen | 5.0 | N/A | Stable |
| 06 | AA2-000-AA1-144-P1-02 | 3ph fault at AA1-144 POI - Scoth - East Towanda 230 kV | 5.0 | N/A | Stable |
| 07 | AA2-000-MOSH-P1-01 | 3ph fault at Moshannon - Quehanna - ELKO 230 kV | 6.0 | N/A | Stable |
| 08 | AA2-000-MOSH-P1-02 | 3ph fault at Moshannon - AA1-085 Tap 230 kV | 6.0 | N/A | Stable |
| 09 | AA2-000-MOSH-P1-03 | 3ph fault at Moshannon -Shawville 230 kV | 6.0 | N/A | Stable |
| 10 | AA2-00-SHAW-P1-01 | 3ph fault at Sahwville - ELKO 230 kV | 5.0 | N/A | Stable |
| 11 | AA2-00-SHAW-P1-02 | 3ph fault at Shawville - Shingle Town 230 kV | 5.0 | N/A | Stable |
| 12 | AA2-00-SHAW-P1-03 | 3ph fault at Shawville G4 | 3.5 | N/A | Stable |
| 13 | AA2-00-SHAW-P1-04 | 3ph fault at Shawville G3 | 3.5 | N/A | Stable |
| 14 | AA2-00-SHAW-P1-05 | 3ph fault at Shawville G1 | 5.0 | N/A | Stable |
| 15 | AA2-00-SHAW-P1-06 | 3ph fault at Shawville G2 | 5.0 | N/A | Stable |
| 16 | AA2-000-AA1-085-P1-01 | 3ph fault at AA1-085 Tap - Milesburg 230 kV | 6.0 | N/A | Stable |
| 17 | AA2-000-AA1-085-P1-02 | 3ph fault at AA1-085 230/34.5/13.2 kV TF1 | 6.0 | N/A | Stable |
| 18 | AA2-000-ELK-P1-01 | 3ph fault at ELK - Shawville 230 kV | 6.0 | N/A | Stable |
| 19 | AA2-000-ELK-P1-02 | 3ph fault at ELK - Carbon Center 230 kV | 6.0 | N/A | Stable |
| 20 | AA2-000-ELK-P1-03 | 3ph fault at ELK - Squab Hollow 230 kV | 6.0 | N/A | Stable |
| 21 | AA2-000-AA2-000-P1-03 | 3ph fault at AA2-00 – New Sub 230/345 kV TF | 5.0 | N/A | Stable |
| 22 | AA2-000-NSUB-P1-01 | 3ph fault at New Sub – Homer City 345 kV | 4.0 | N/A | Stable |
| 23 | AA2-000-NSUB-P1-02 | 3ph fault at New Sub – Mainsburg 345 kV | 4.0 | N/A | Stable |
| **Criteria = TPL 001-4_P2** | | | | | |
| 24 | AA2-000-AA2-000-P2-01 | SLG fault at AA2-000 230 kV Bus, Loss of AA2-000 - Lobo - Marshall/Laurel Hill 230 kV | 5.0 | N/A | Stable |
| 25 | AA2-000-AA2-000-P2-02 | SLG fault at AA2-000 230 Kv Bus, Loss of AA2-00 – New Sub 230/345 kV TF | 5.0 | N/A | Stable |
| 26 | AA2-000-MARS-P2-01 | SLG fault at Marshall 230 kV 230 kV Bus, Loss of Marshall - Laurel Hill 230 kV, Loss of Gen | 5.0 | N/A | Stable |
| 27 | AA2-000-MARS-P2-02 | SLG fault at Marshall 230 kV Bus, Loss of Marshall - Grover - AA1-144 Tap 230 kV | 5.0 | N/A | Stable |
| 28 | AA2-000-AA1-144-P2-01 | SLG fault at AA1-144 POI 230 kV Bus,AA1-144 POI - AA1-144 Main 230 kV, Loss of Gen | 5.0 | N/A | Stable |
| 29 | AA2-000-AA1-144-P2-02 | SLG fault at AA1-144 POI 230 kV Bus, Loss of AA1-144 POI - Scoth - East Towanda 230 kV | 5.0 | N/A | Stable |
| 30 | AA2-000-MOSH-P2-01 | SLG fault at Moshannon 230 kV Bus, Loss of Moshannon - Quehanna - ELKO 230 kV | 5.0 | N/A | Stable |
| 31 | AA2-000-MOSH-P2-02 | SLG fault at Moshannon 230 kV Bus, Loss of Moshannon - AA1-085 Tap 230 kV | 6.0 | N/A | Stable |
| 32 | AA2-000-MOSH-P2-03 | SLG fault at Moshannon 230 kV Bus, Loss of Moshannon - Shawville 230 kV | 6.0 | N/A | Stable |

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| No. | Contingency ID | Type of Fault | Clearing time (cycles) | | Results |
|---|---|---|---|---|---|
| | | | Normal | Delayed | |
| 33 | AA2-00-SHAW-P2-01 | SLG fault at Shawville 230 kV Bus, Loss of Sahwville - ELKO 230 kV + Shawville - Shingle Town 230 kV | 5.0 | N/A | Stable |
| 34 | AA2-00-SHAW-P2-02 | SLG fault at Shawville 230 kV Bus, Loss of Shawville G4 + Shawville G2 | 5.0 | N/A | Stable |
| 35 | AA2-00-SHAW-P2-03 | SLG fault at Shawville 230 kV Bus, Loss of Shawville G3 + Shawville G1 + Moshannon -Shawville 230 kV | 5.0 | N/A | Stable |
| 36 | AA2-000-AA1-085-P2-01 | SLG fault at AA1-085 Tap 230 kV Bus, Loss of AA1-085 Tap - Milesburg 230 kV | 6.0 | N/A | Stable |
| 37 | AA2-000-AA1-085-P2-02 | SLG fault at AA1-085 Tap 230 kV Bus, Loss of AA1-085 230/34.5/13.2 kV TF1 | 6.0 | N/A | Stable |
| 38 | AA2-000-ELK-P1-02 | SLG fault atELK 230 kV Bus, Loss of ELK 230 kV Bus | 6.0 | N/A | Stable |
| 39 | AA2-000-NSUB-P1-01 | SLG fault at New Sub 345 kV Bus, Loss of New Sub – AA2-00 345/230 kV TF | 4.0 | N/A | Stable |
| 40 | AA2-000-NSUB-P1-01 | SLG fault at New Sub 345 kV Bus, Loss of New Sub – Mainburg 345 kV | 4.0 | N/A | Stable |
| **Criteria = TPL 001-4_P4** | | | | | |
| 41 | AA2-000-AA2-000-P4-01 | SLG fault at AA2-000 – New Sub (230/345 kV TF), SB @ AA2-000, Loss of AA2-000 - Lobo - Marshall/Laurel Hill 230 kV | 5.0 | 16.0 | Stable |
| 42 | AA2-000-AA2-000-P4-01 | SLG fault at AA2-000 - Lobo - Marshall/Laurel Hill 230, Sb @ AA2-000, Loss of AA2-000 – New Sub (230/345 kV TF) | 5.0 | 16.0 | Stable |
| 43 | AA2-000-AA2-000-P4-01 | SLG fault at AA2-000 - Lobo - Marshall/Laurel Hill 230, SB @ AA2-000, Loss of AA2_000 - Chapman - Moshannon 230 kV | 5.0 | 16.0 | Stable |
| 44 | AA2-000-AA2-000-P4-01 | SLG fault at AA2_000 - Chapman - Moshannon 230 kV, SB @ AA2-000, Loss of AA2-000 - Lobo - Marshall/Laurel Hill 230 | 5.0 | 16.0 | Stable |
| 45 | AA2-000-MARS-P4-01 | SLG fault at Marshal - Lobo - AA2-000 Tap230 kV, SB '1' @ Marshall, Loss of Marshall - Laurel Hill 230 kV + Marshall - Grover - AA1-144 Tap 230 kV | 5.0 | 16.0 | Stable |
| 46 | AA2-000-MARS-P4-02 | SLG fault at Marshall - Laurel Hill 230 kV, Loss of Gen, SB '2' @ Marshall, Loss of AA2-000 - Lobo - Marshall/Laurel Hill 230 kV + Marshall - Grover - AA1-144 Tap 230 kV | 5.0 | 16.0 | Stable |
| 47 | AA2-000-MARS-P4-03 | SLG fault at Marshall - Grover - AA1-144 Tap 230 kV, SB '1' @ Marshall, Loss of Marshall - Laurel Hill 230 kV, Loss of Gen + AA2-000 - Lobo - Marshall/Laurel Hill 230 kV | 5.0 | 16.0 | Stable |
| 48 | AA2-000-AA1-144-P4-01 | SLG fault at AA1-144 POI - AA1-144 Main 230 kV, Loss of Gen, SB @ AA1-144, Loss of AA1-144 POI - Scoth - East Towanda 230 kV + Marshall - Grover - AA1-144 Tap 230 kV | 5.0 | 16.0 | Stable |
| 49 | AA2-000-AA1-144-P4-02 | SLG fault at AA1-144 POI - Scoth - East Towanda 230 kV, Loss of Gen, SB @ AA1-144, Loss of AA1-144 POI - AA1-144 Main 230 kV, Loss of Gen + Marshall - Grover - AA1-144 Tap 230 kV | 5.0 | 16.0 | Stable |
| 50 | AA2-000-MOSH-P4-01 | SLG fault on Moshannon - Chapman - AA2-000 Tap, SB '4' @ Moshnnon, Loss of Moshannon -Shawville 230 kV | 6.0 | 20.0 | Stable |
| 51 | AA2-000-MOSH-P4-02 | SLG fault onMoshannon -Shawville 230 kV, SB '4' @ Moshnnon, Loss of Moshannon - Chapman - AA2-000 Tap | 6.0 | 20.0 | Stable |
| 52 | AA2-000-MOSH-P4-03 | SLG fault on Moshannon - Chapman - AA2-000 Tap, SB '3' @ Moshnnon, Loss ofMoshannon - Quehanna - ELKO 230 kV | 6.0 | 20.0 | Stable |
| 53 | AA2-000-MOSH-P4-04 | SLG fault on Moshannon - Quehanna - ELKO 230 kV, SB '3' @ Moshnnon, Loss of Moshannon - Chapman - AA2-000 Tap | 6.0 | 20.0 | Stable |
| 54 | AA2-000-MOSH-P4-05 | SLG fault on Moshannon - Quehanna - ELKO 230 kV, SB '2' @ Moshannon, Loss of Moshannon - AA1-085 Tap 230 kV | 6.0 | 20.0 | Stable |
| 55 | AA2-000-MOSH-P4-06 | SLG fault on Moshannon - AA1-085 Tap 230 kV, SB '2' @ Moshannon, Loss of Moshannon - Quehanna - ELKO 230 kV | 6.0 | 20.0 | Stable |
| 56 | AA2-000-MOSH-P4-07 | SLG fault at Moshannon -Shawville 230 kV, SB '1' @ Moshannon, Loss of Moshannon - AA1-085 Tap 230 kV | 6.0 | 20.0 | Stable |
| 57 | AA2-000-MOSH-P4-08 | SLG fault atMoshannon - AA1-085 Tap 230 kV, SB '1' @ Moshannon, Loss ofMoshannon -Shawville 230 kV | 6.0 | 20.0 | Stable |

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| No. | Contingency ID | Type of Fault | Clearing time (cycles) | | Results |
|---|---|---|---|---|---|
| | | | Normal | Delayed | |
| 58 | AA2-00-SHAW-P4-01 | SLG fault on G1-G3 Bus, SB @ Shawville, Loss of Shawville - Moshannon 230 kV | 5.0 | 16.0 | Stable |
| 59 | AA2-00-SHAW-P4-02 | SLG fault on Sahwville - ELKO 230 kV + Shawville - Shingle Town 230 kV, SB @ Shawville, Loss of Shaville G4 and G2 | 5.0 | 16.0 | Stable |
| 60 | AA2-00-SHAW-P4-03 | SLG fault on Shaville G4 and G2, SB @ Shawville, Loss of Sahwville - ELKO 230 kV + Shawville - Shingle Town 230 kV | 5.0 | 16.0 | Stable |
| 61 | AA2-000-AA1-085-P4-01 | SLG fault on AA1-085 Tap - Milesburg 230 kV, SB @ AA1, Loss of AA1-085 230/34.5/13.2 kV TF1 + Moshannon - AA1-085 Tap 230 kV | 6.0 | 20.0 | Stable |
| 62 | AA2-000-AA1-085-P4-02 | SLG fault at AA1-085 230/34.5/13.2 kV TF1, SB @ AA1-085, Loss of AA1-085 Tap - Milesburg 230 kV + Moshannon - AA1-085 Tap 230 kV | 6.0 | 20.0 | Stable |
| 63 | AA2-000-ELK-P4-01 | SLG fault at ELKO - Quehanna - Moshannon 230 kV, SB @ ELKO, Loss of ELKO Bus | 6.0 | 20.0 | Stable |
| 64 | AA2-000-ELK-P4-02 | SLG fault atELK - Shawville 230 kV, SB @ ELKO, Loss of ELKO Bus | 6.0 | 20.0 | Stable |
| 65 | AA2-000-ELK-P4-03 | SLG fault at ELK - Carbon Center 230 kV, SB @ ELKO, Loss of ELKO Bus | 6.0 | 20.0 | Stable |
| 66 | AA2-000-ELK-P4-04 | SLG fault at ELK - Squab Hollow 230 kV, SB @ ELKO, Loss of ELKO Bus | 6.0 | 20.0 | Stable |
| 67 | AA2-000-NEWS-P4-01 | SLG fault on New Sub – Mainsburg 345 kV, SB @ New Sub 345 kV, Loss of New Sub – Homer City 345 kV + New Sub – Homer City 345 kV | 4.0 | 13.0 | Stable |
| 68 | AA2-000-NEWS-P4-02 | SLG fault on of New Sub – Homer City 345 kV , SB @ New Sub 345 kV, Loss of New Sub – Mainsburg 345 kV + New Sub – Homer City 345 kV | 4.0 | 13.0 | Stable |
| **Criteria = TPL 001-4_P4** | | | | | |
| 69 | AA2-000-AA2-000-P5-01 | SLG fault at 80% on AA2-000 - Lobo - Marshall/Laurel Hill 230 kV | 5.0 | 34.0 | Stable |
| 70 | AA2-000-AA2-000-P5-02 | SLG fault at 80% on AA2_000 - Chapman - Moshannon 230 kV | 5.0 | 34.0 | Stable |

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## Appendix B: Breaker Diagram

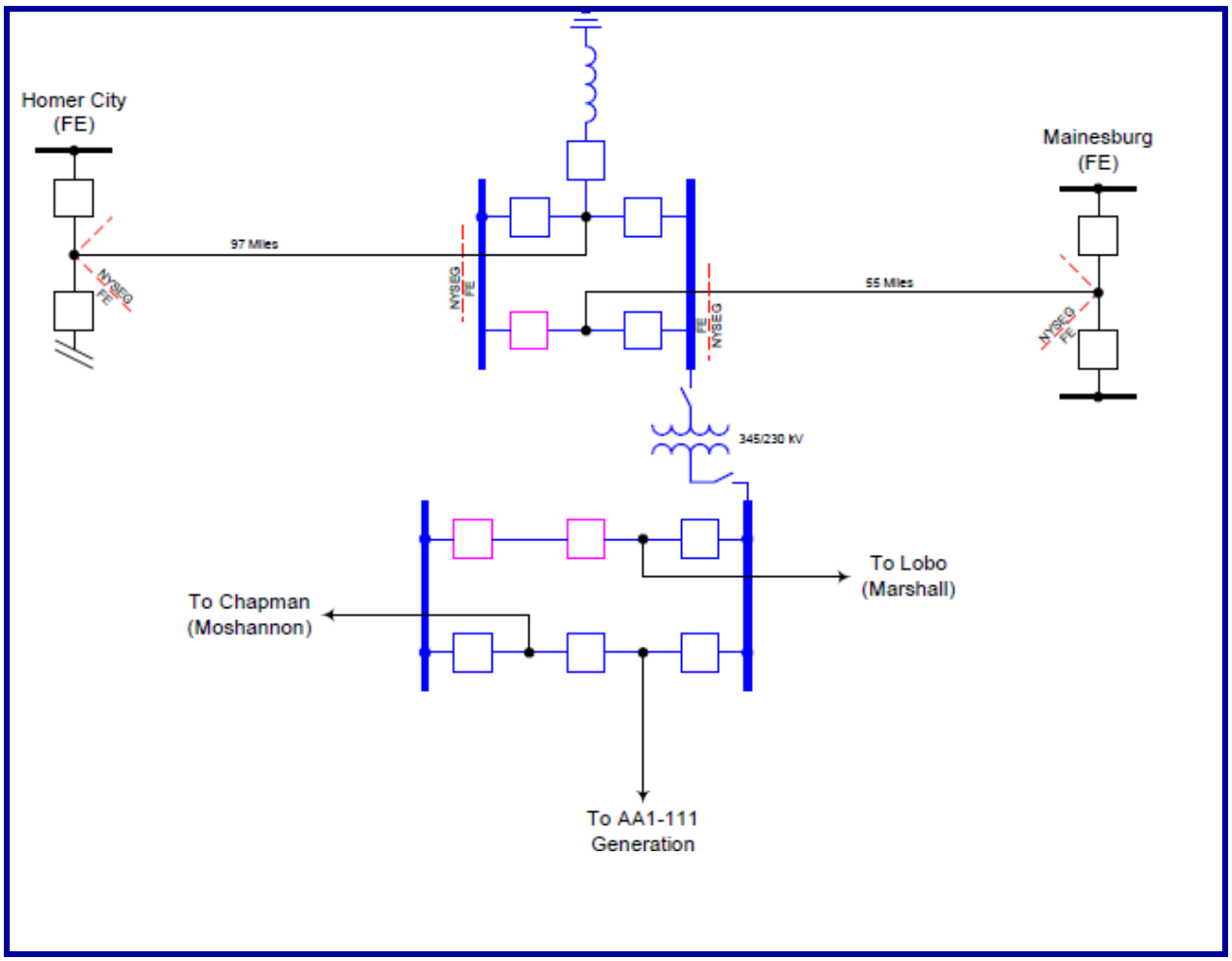


Figure B-1: PJM AA2-000 modeling details

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# Appendix C: Power Flow and Dynamic Models

C.1) PSS/E Models

PSS/E Models for AA2-000 Generator

Generator model: GENROU
Excitation model: ESST4B
Governor model: GGOV1
Power System Stabilizer model: PSS2B

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## C.2) Power Flow Model Data

```
BAT_LTAP,200908,200909,'1', 0.497,918922,'AA1-111_TAP', 230.0

Version 32

RDCH

1

918920,'AA1-111_GEN ',  23.5000,2, 226, 210, 258,1.01774, 63.5020

918922,'AA1-111_TAP ', 230.0000,1, 226, 210, 258,1.02170, 55.4566

0 / END OF BUS DATA, BEGIN LOAD DATA

918920,'1 ',1, 226, 210, 9.400, 5.800, 0.000, 0.000, 0.000, 0.000, 258,1

0 / END OF LOAD DATA, BEGIN FIXED SHUNT DATA

0 / END OF FIXED SHUNT DATA, BEGIN GENERATOR DATA

918920,'1 ', 472.400, 16.270, 250.000, -190.000,1.02170,918922, 570.000, 0.00000E+0, 2.05000E-1, 0.00000E+0,

918922,918920, 0,'1 ',1,2,1, 0.00000E+0, 0.00000E+0,2,'              ',1, 258,1.0000
 2.00000E-3, 1.00000E-1, 318.00

1.00000, 242.000,   0.000,   318.00,   423.00,   528.00, 0,       0, 1.07500, 0.97500, 1.07500, 0.97500, 5, 0, 0.00000, 0.00000, 0.000

1.00000, 23.500

0 / END OF TRANSFORMER DATA, BEGIN AREA DATA

 226,     0,  1744.000,     5.000,'PENELEC        '

0 / END OF AREA DATA, BEGIN TWO-TERMINAL DC DATA

0 / END OF TWO-TERMINAL DC DATA, BEGIN VSC DC LINE DATA
```

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## C.3) Dynamic Data

```
/PSSE Version 32


/ ************************************************************
/ *** AA1-111 Natural Gas Facility - 472.4 MW              ***
/ ************************************************************



/ Natural Gas Facility
918920  'GENROU'       1              6.177   0.034   0.59    0.067
                                     4.8121  2.5     1.85    1.78    0.25
                                     0.44    0.205   0.16    0.0342  0.2167          /


918920  'GGOV1'        1              -2              1               0               0.2
                                      0.05           -0.05            15             0
        0
                                      1              0.85            -0.1            0.1
        1.667
                                      0              1               0               0
        1
                                      0.45            0.3            1.203           0
        2
                                      -2             0.0014           99             10
        0.1
                                      393            0               10              3
        99
                                      -99
                        /
```

## C.4) PSS/E Single Line Diagram

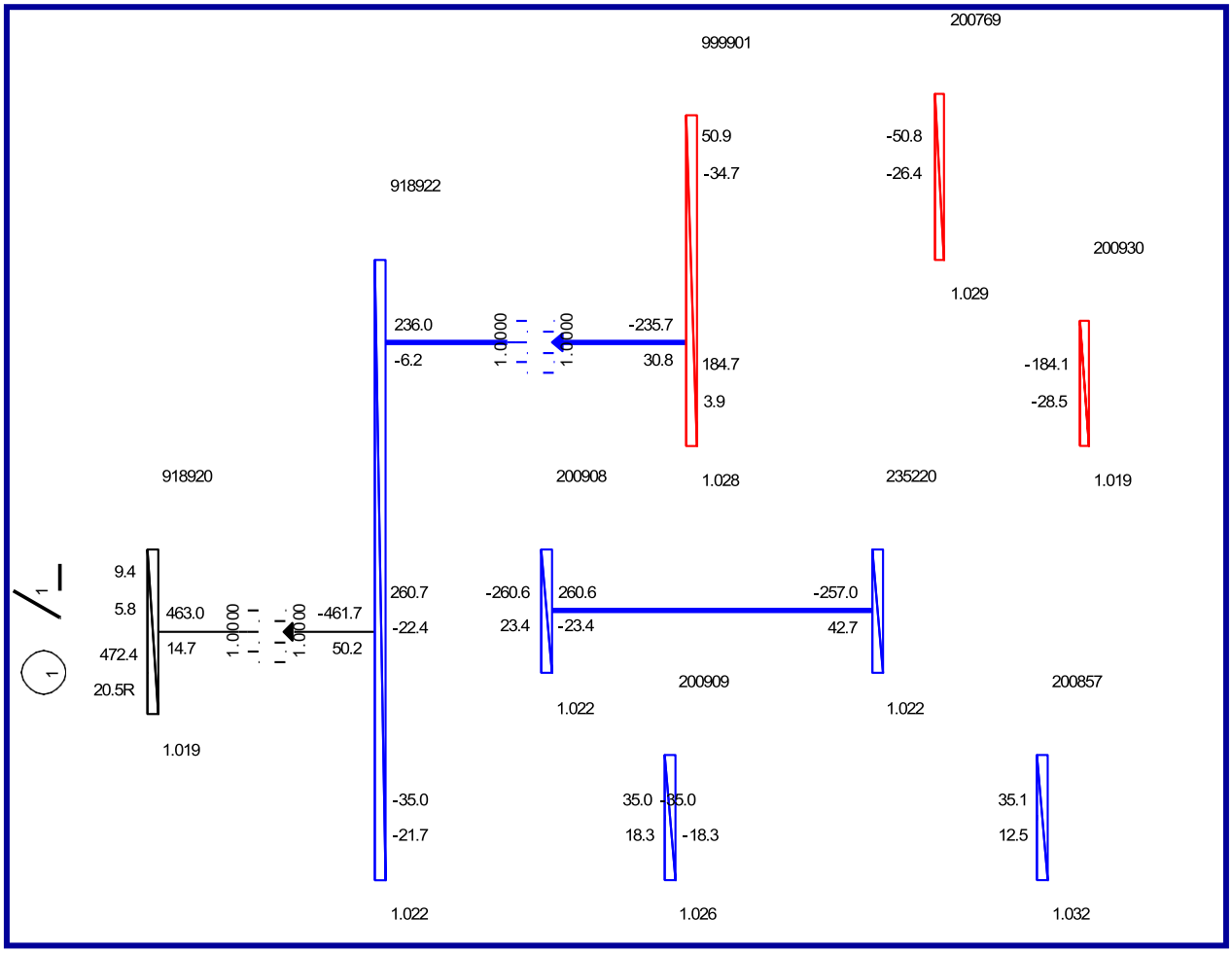


Figure C-1: Single-line diagram for AA2-000 (LL case) (Breaker information not shown)

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## C.5) Voltage Schedules and Generation (stressed case used for study) Machines data

| Bus Number | Bus Name | Id | Code | VSched (pu) | Remote Bus Number | In Service | Pgen (MW) | Pmax (MW) | Pmin (MW) | Qgen (Mvar) | Qmax (Mvar) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200665 | 26SHAWVL 3 22.000 | 3 | -2 | 1.0391 | 200710 | 1 | 175 | 175 | 120 | 54 | 54 |
| 200666 | 26SHAWVL 4 22.000 | 4 | -2 | 1.0391 | 200726 | 1 | 175 | 175 | 120 | 40 | 40 |
| 200715 | 26SHAWVL 1 18.000 | 1 | -2 | 1.0174 | 200714 | 1 | 122 | 122 | 62 | 0 | 59 |
| 200722 | 26SHAWVL 2 18.000 | 2 | -2 | 1.0174 | 200714 | 1 | 125 | 125 | 62 | -45 | 67 |
| 200837 | 26HOMER C1 20.000 | 1 | 2 | 1.0304 | 200767 | 1 | 620 | 620 | 300 | 87.027 | 345 |
| 200838 | 26HOMER C2 20.000 | 2 | 2 | 1.029 | 200769 | 1 | 614 | 614 | 300 | 68.798 | 345 |
| 200839 | 26HOMER C3 24.000 | 3 | 2 | 1.029 | 200769 | 1 | 650 | 650 | 300 | 68.798 | 235 |
| 200894 | LAURHILL-G 34.500 | W1 | -2 | 1.0174 | 200857 | 1 | 56 | 56 | 0 | 0 | 0 |
| 200917 | P28 0.6900 | 1 | -2 | 1.0174 | 200877 | 1 | 147.8 | 147.8 | 0 | 0 | 0 |
| 203261 | 26BLOSSBCT 34.500 | 1 | -2 | 1.0152 | 0 | 1 | 17.81 | 19 | 0 | 0 | 8 |
| 203283 | 26MANOR 34.500 | 1 | -2 | 1.0145 | 0 | 0 | 1.406 | 1.5 | 0 | 0 | 0 |
| 235971 | 01SQUABHLLW 230.00 | SV | -2 | 1.02 | 0 | 1 | 0 | 0 | 0 | 0 | 250 |
| 236828 | 01GRAYMONT 46.000 | 1 | -2 | 1 | 0 | 0 | 3.826 | 4 | 0 | 0 | 0 |
| 297050 | V2-019 E 115.00 | 1 | -2 | 1.0174 | 0 | 0 | 0.477 | 0.5 | 0 | 0.24 | 0.24 |
| 907461 | X1-109 G1 23.000 | 1 | 2 | 1.0217 | 200675 | 1 | 462 | 462 | 92 | 97.649 | 150 |
| 907462 | X1-109 G2 23.000 | 1 | 2 | 1.0217 | 200675 | 1 | 462 | 462 | 92 | 97.649 | 150 |
| 910521 | X3-003 GT 13.800 | 1 | 2 | 1.017 | 200699 | 1 | 70 | 70 | 10 | 5.7925 | 25 |
| 910541 | X3-005 C 13.200 | 1 | -2 | 1.016 | 0 | 1 | 2.481 | 3.4 | 0 | 0 | 0 |
| 910542 | X3-005 E 13.200 | 1 | -2 | 1.016 | 0 | 1 | 5.6 | 5.6 | 0 | 0 | 0 |
| 913191 | Y1-047 OP134.500 | 1 | -2 | 1.067 | 0 | 1 | 15.4 | 15.4 | 0 | 7.392 | 7.392 |
| 913311 | Y1-071 138.00 | 1 | -2 | 0.996 | 0 | 1 | 5.724 | 6 | 0 | 3.168 | 3.168 |
| 914151 | Y2-060 34.500 | 1 | -2 | 1.067 | 0 | 0 | 0 | 3.5 | 0 | 0 | 1.68 |
| 918703 | AA1-085_GEN 0.6900 | 1 | 2 | 1.0217 | 918700 | 1 | 82 | 82 | 0 | 10.442 | 16.65 |
| 918920 | AA1-111_GEN 23.500 | 1 | 2 | 1.0217 | 918922 | 1 | 472.4 | 472.4 | 0 | 20.539 | 250 |
| 919202 | AA1-144 GEN113.800 | G1 | 2 | 1.0217 | 919200 | 1 | 68.5 | 68.5 | 0 | -21.554 | 62 |
| 919202 | AA1-144 GEN113.800 | S1 | 2 | 1.0217 | 919200 | 1 | 14 | 14 | 0 | -4.4053 | 9.9 |
| 919203 | AA1-144 GEN213.800 | G2 | 2 | 1.0217 | 919200 | 1 | 68.5 | 68.5 | 0 | -21.554 | 62 |
| 919203 | AA1-144 GEN213.800 | S2 | 2 | 1.0217 | 919200 | 1 | 14 | 14 | 0 | -4.4053 | 9.9 |
| 919990 | AA2-083_GEN 13.800 | 1 | 2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -2.002 | 5.8 |
| 919990 | AA2-083_GEN 13.800 | 2 | 2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -2.002 | 5.8 |
| 919990 | AA2-083_GEN 13.800 | 3 | 2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -2.002 | 5.8 |
| 920351 | AA2-133 GEN 13.800 | 1 | -2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -3.2 | 5.8 |
| 920351 | AA2-133 GEN 13.800 | 2 | -2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -3.2 | 5.8 |
| 920351 | AA2-133 GEN 13.800 | 3 | -2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -3.2 | 5.8 |
| 920370 | AA2-135 GEN 13.800 | 1 | 2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | 0.1425 | 5.8 |
| 920370 | AA2-135 GEN 13.800 | 2 | 2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | 0.1425 | 5.8 |
| 920370 | AA2-135 GEN 13.800 | 3 | 2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | 0.1425 | 5.8 |
| 920610 | AA2-167 GEN 13.800 | 1 | -2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -3.2 | 5.8 |
| 920610 | AA2-167 GEN 13.800 | 2 | -2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -3.2 | 5.8 |
| 920610 | AA2-167 GEN 13.800 | 3 | -2 | 1 | 0 | 1 | 7.01 | 7.01 | 0 | -3.2 | 5.8 |

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## Plant data

| Bus Number | Bus Name | Code | P Gen | Q Gen | Q Max | Q Min | VSched (pu) | Remote Bus Number | Remote Bus Name | Voltage (pu) | RMPCT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200665 | 26SHAWVL 3 22.000 | -2 | 175 | 54 | 54 | -16 | 1.0391 | 200710 | 26SHAWVL 1 230.00 | 1.0237 | 100 |
| 200666 | 26SHAWVL 4 22.000 | -2 | 175 | 40 | 40 | -14.2 | 1.0391 | 200726 | 26SHAWVL 2 230.00 | 1.0234 | 100 |
| 200715 | 26SHAWVL 1 18.000 | -2 | 122 | 0 | 59 | 0 | 1.0174 | 200714 | 26SHAWVL 1 115.00 | 1.0339 | 100 |
| 200722 | 26SHAWVL 2 18.000 | -2 | 125 | -45 | 67 | -45 | 1.0174 | 200714 | 26SHAWVL 1 115.00 | 1.0339 | 100 |
| 200837 | 26HOMER C1 20.000 | 2 | 620 | 87 | 345 | -140 | 1.0304 | 200767 | 26HOMER CT 230.00 | 1.0304 | 100 |
| 200838 | 26HOMER C2 20.000 | 2 | 614 | 68.8 | 345 | -100 | 1.029 | 200769 | 26HOMER CY 345.00 | 1.029 | 100 |
| 200839 | 26HOMER C3 24.000 | 2 | 650 | 68.8 | 235 | -140 | 1.029 | 200769 | 26HOMER CY 345.00 | 1.029 | 100 |
| 200894 | LAURHILL-G 34.500 | -2 | 56 | 0 | 0 | 0 | 1.0174 | 200857 | LAURHILL 230.00 | 1.0316 | 100 |
| 200917 | P28 0.6900 | -2 | 148 | 0 | 0 | 0 | 1.0174 | 200877 | P28 115.00 | 1.017 | 100 |
| 203261 | 26BLOSSBCT 34.500 | -2 | 17.8 | 0 | 8 | 0 | 1.0152 | 0 | | 1.039 | 100 |
| 203283 | 26MANOR 34.500 | -2 | 0 | 0 | 0 | 0 | 1.0145 | 0 | | 1.0294 | 100 |
| 235971 | 01SQUABHLLW 230.00 | -2 | 0 | 0 | 250 | 0 | 1.02 | 0 | | 1.0244 | 100 |
| 236828 | 01GRAYMONT 46.000 | -2 | 0 | 0 | 0 | 0 | 1 | 0 | | 1.0243 | 100 |
| 297050 | V2-019 E 115.00 | -2 | 0 | 0 | 0 | 0 | 1.0174 | 0 | | 1.0185 | 100 |
| 907461 | X1-109 G1 23.000 | 2 | 462 | 97.6 | 150 | -180 | 1.0217 | 200675 | 26E.TWANDA 230.00 | 1.0217 | 8 |
| 907462 | X1-109 G2 23.000 | 2 | 462 | 97.6 | 150 | -180 | 1.0217 | 200675 | 26E.TWANDA 230.00 | 1.0217 | 8 |
| 910521 | X3-003 GT 13.800 | 2 | 70 | 5.8 | 25 | -25 | 1.017 | 200699 | 26MEHOP 3 115.00 | 1.017 | 9 |
| 910541 | X3-005 C 13.200 | -2 | 2.5 | 0 | 0 | 0 | 1.016 | 0 | | 1.0113 | 100 |
| 910542 | X3-005 E 13.200 | -2 | 5.6 | 0 | 0 | 0 | 1.016 | 0 | | 1.0113 | 100 |
| 913191 | Y1-047 OP134.500 | -2 | 15.4 | 7.4 | 7.4 | -5.1 | 1.067 | 0 | | 1.0582 | 100 |
| 913311 | Y1-071 138.00 | -2 | 5.7 | 3.2 | 3.2 | -2.2 | 0.996 | 0 | | 0.9743 | 100 |
| 914151 | Y2-060 34.500 | -2 | 0 | 0 | 0 | 0 | 1.067 | 0 | | 1.058 | 100 |
| 918703 | AA1-085_GEN 0.6900 | 2 | 82 | 10.4 | 16.6 | -23.9 | 1.0217 | 918700 | AA1-085_TAP 230.00 | 1.0217 | 100 |
| 918920 | AA1-111_GEN 23.500 | 2 | 472 | 20.5 | 250 | -190 | 1.0217 | 918922 | AA1-111_TAP 230.00 | 1.0217 | 100 |
| 919202 | AA1-144 GEN113.800 | 2 | 82.5 | -26 | 71.9 | -34.2 | 1.0217 | 919200 | AA1-144 POI 230.00 | 1.0217 | 100 |
| 919203 | AA1-144 GEN213.800 | 2 | 82.5 | -26 | 71.9 | -34.2 | 1.0217 | 919200 | AA1-144 POI 230.00 | 1.0217 | 100 |
| 919990 | AA2-083_GEN 13.800 | 2 | 21 | -6 | 17.4 | -9.6 | 1 | 0 | | 1 | 100 |
| 920351 | AA2-133 GEN 13.800 | -2 | 21 | -9.6 | 17.4 | -9.6 | 1 | 0 | | 1.005 | 100 |
| 920370 | AA2-135 GEN 13.800 | 2 | 21 | 0.4 | 17.4 | -9.6 | 1 | 0 | | 1 | 100 |
| 920610 | AA2-167 GEN 13.800 | -2 | 21 | -9.6 | 17.4 | -9.6 | 1 | 0 | | 1.0055 | 100 |

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