Generation Interconnection Facility Study Report

For

PJM Generation Interconnection Request Queue Position Z2-009

East Hazelton-Harwood 69kV

November 2015

A. Transmission Owner Facilities Study Summary

1. Description of Project

Queue Z2-009 is a EDF Renewable Development, Inc. request to interconnect a proposed 52 MW (6.7 MW capacity) wind farm to the Harwood - E. Hazelton #2 69 kV transmission line. The Queue Z2-009 generation interconnection is scheduled for commercial operation on December 31, 2016. This study does not imply a PPL Electric Utilities (PPL EU) commitment to this in-service date.

The Z2-009 project can be connected to PPL EU's 69 kV transmission system by tapping the White Haven Tap line off Harwood - E. Hazelton #2 69 kV line and extending approximately 500 feet of single circuit transmission line to the Interconnection Customer's (IC's) Substation. The Point of Interconnection (POI) will be where the PPL EU transmission line lands on the customer's dead-end structure inside the IC's yard. Please see Attachment 1for a one-line diagram of the POI. IC has not provided to PPL its substation site plan in relation to PPL's transmission line. Therefore, the scope and estimate of the attachment facilities lack some details and accuracy of a normal Facilities Study. Once more details are known about the exact location and positioning of the customer's deadend structure, the scope and estimate can be refined. The customer should be aware that the costs presented in this Facilities Study are liable to change.

Z2-009 will interconnect with the PPL EU transmission system at the White Haven Tap 69kV line off Harwood - E. Hazelton #2 line. The point of interconnection (POI) will occur at the dead-end structure at the generation substation located approximately near 40°59'19.88"N 75°47'56.71"W. The Z2-009 project would be connected to the PPL EU system through a 69 kV tap off the existing White Haven Tap 69 kV line to the customer's proposed substation.

2. Amendments to the System Impact Study data or System Impact Study Results

None.

3. Interconnection Customer's Submitted Milestone Schedule

December 31, 2016 – Requested In Service Date

4. Description of Facilities Included in the Facilities Study

Attachment Facilities

- New 69kV transmission tap (PJM Network Upgrade Number n4397)

Direct Connection Facilities

- None

Non-Direct Connection Facilities

- Harwood substation work (PJM Network Upgrade Number n4398)

5. Total Costs of Transmission Owner Facilities included in Facilities Study

The 69 kV connection estimate is based on the assumptions stated in the following Transmission Attachment Facilities, Direct Connection, and Substation Non- Direct Connection Work sections.

The transmission and substation costs given above exclude any applicable state or federal taxes. If at a future date Federal CIAC (cost in aid of construction) taxes are deemed necessary by the IRS for this project, both PJM and PPL EU shall be reimbursed by the Interconnection Customer for such taxes.

Activity	NUN	Cost	
Attachment Facilities			
New 69kV transmission tap	N4397	$	2,330,000
Direct Connection Facilities			
None		$	0
Non-Direct Connection Facilities			
Harwood substation work	N4398	$	150,000
Total Cost Estimate		**$**	**2,480,000**

6. Summary of Milestone Schedules for Completion of Work Included in Facilities Study:

The estimated PPL EU elapsed time to complete the 69 kV Attachment Facilities and Non-Direct connection substation work is approximately 18 months after the receipt of a fully executed ISA/CSA.

The schedule for the 69 kV substation work to accommodate Z2-009 would depend on the project's start date. The work to accommodate Z2-009 will require substation facility outages. PPL EU's outage windows for construction are typically available in the spring and fall of the year. Missing an outage window could result in project delays.

The transmission and substation work can be completed concurrently. PPL EU will commence siting, engineering design, material purchase and construction of the facilities identified in this study after receiving written authorization by PJM to begin work. This time frame is contingent upon the acquisition of all ROW in the stated time frame before the start of construction and detailed design.

ISA/ICSA Executed	January 1, 2016
Begin Engineering	February 1, 2016
Complete Engineering	November 1, 2016
Begin Construction	December 1, 2016
Back-feed to IPP	June 1, 2017

B. Transmission Owner Facilities Study Results

1. Transmission Lines – New

New 69kV transmission tap

PJM Network Upgrade Number n4397

IC will provide a suitable route for the 100 feet wide Right-of-Way (ROW) needed to construct the approximately 500 ft. 69 kV single circuit transmission line using 556 Kcmil ACSR conductors with optical ground wire (OPGW) to the dead end structure inside the customer's substation (POI).

- The tap will be designed to 69 kV 760BIL standards by utilizing 556.5 ACSR power conductors and 2 – 0.567" OPGW fiber optic cables in the shield wire position
- The tap will begin from structure number 53851N30533
- The total distance of the tap will be approximately 500 feet from this structure.
- Existing wood pole 53851N30533 will be replaced with a custom steel tap pole
- Install new LD steel pole angle structure 200 feet from new tap pole.
- Install substation DE angle structure 200 feet from previous angle structure.
- 1 MOLBAB structure will be installed on the White Haven side of new LD steel tap pole along the White Haven Tap line, approximately 100' from the new LD tap pole.

The transmission attachment facilities work includes the installation of one MOLBAB (Motor Operated Load Break Air Break) switch on the PPL EU White Haven Tap off Harwood-East Hazleton #2 69 kV line as described above. The switch would be installed on a custom designed steel pole with a concrete foundation. See Attachment 1for the connection schematic.

2. Transmission Line – Upgrades

None.

3. New Substation/Switchyard Facilities

None.

4. Upgrades to Substation / Switchyard Facilities

Harwood substation work

PJM Network Upgrade Number n4398

The protection systems at the remote ends of the 69kV line will be modified to support this interconnection. To accommodate Z2-009, the following upgrades are required at PPL EU's Harwood 230-69kV Substations:

- Update relay to Microprocessor based on the East Hazleton #2 69kV line at Harwood

- Install 1 Relay (DTT) Cabinet at Harwood
- Install new phone based line protection equipment at Harwood
- Install Potential Transformer (PT) at Harwood necessary for sync check of East Hazleton #2 69kV transmission line
- Modify the controls of the East Hazleton #2 69kV circuit breaker at Harwood for trip and close
- Modify SCADA for new alarms
- Modify AMS (Alarm Management System)
- Perform system checks and test equipment before placing in service

5. Metering & Communications

PPL EU Requirements

Metering Equipment Installation at the POI (Point of Interconnection)
Installation of revenue grade metering equipment will be required at the Z2-009 Point of Interconnection at the Interconnection Customer dead-end structure. PPL EU will design and supply the required metering equipment but all the installation cost would be borne by the developer including CT/PTs. All metering equipment must meet applicable PPL EU 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 metering equipment should be housed in a control cabinet or similar enclosure and must be accessible to PPL EU metering personnel.

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. Any data from the PPL EU revenue meters can be transferred by fiber optic link to the PJM RTU located at the IPP facility.

SCADA Equipment Requirements
PPL EU will require installation of PPL EU approved SCADA equipment that will connect to its existing SCADA system to provide real time values of KW, KVAR, and kV metering data at the POC. SCADA equipment will also provide capability to trip and the status monitoring of the POC isolating circuit breaker. In addition to that, monitoring of other abnormal conditions at developers plant will be provided where deemed necessary. PPL EU will provide detailed specifications and design drawings for this equipment.

Telephone Circuit Requirements (At the IPP)
PPL EU will require a communication path for SCADA, DTT, and voice circuits. PPL EU anticipates that telephone circuits will be required to establish these paths. The Interconnection Customer will be responsible to procure the following:

1. A 4-wire dedicated FDDA-type phone line for SCADA
2. A normal dialup telephone line for voice communication

Phone lines tend to be long lead-time items and must be in place and operational for equipment testing. The Interconnection Customer should investigate with the local phone company the possibility of obtaining this type of service at their facility.

All installation, maintenance, and monthly lease or billing charges for communications facilities are the responsibility of the Interconnection Customer.

PJM SCADA Equipment Requirement

The Interconnection Customer will be required to install equipment necessary to provide Revenue Metering (KWH, KVARH) and real time data (KW, KVAR) to PJM via the SCADA equipment in compliance with the requirements in PJM Manuals M-01 and M-14D, and PJM Tariff Sections 24.1 and 24.2 available at http://www.pjm.com.

6. Environmental, Real Estate and Permitting Issues

To avoid duplication of costs and efforts, PPL EU requires that the IC obtain all environmental approvals required for construction of the generating station and share pertinent details with PPL EU prior to PPL EU beginning work on the line siting.

7. Summary of Results of Study

Description	Project Totals
Direct material costs	$ 925,000
Indirect material costs	$ 115,000
Direct labor costs	$ 1,200,000
Indirect labor costs	$ 240,000
Total Costs:	**$ 2,480,000**

Transmission Owner Assumptions in Developing the Cost Estimates

- For the custom-designed steel transmission poles, the lead-time is approximately 32 to 42 weeks. It is estimated that approximately one custom designed steel poles will be needed for this project.
- During construction, if extreme weather conditions or other system safety concerns arise, field construction may need to be rescheduled, which could possibly delay the schedule.
- For the new 69 kV tap from Z2-009 to the White Haven Tap 69kV line, it is assumed land will be provided and the tap would be owned by PPL EU.
- No environmental, real estate, or permitting issues were reviewed for the estimate of this project due to unavailable of IC's site plan.

- This estimate assumes that suitable facility outages can be schedule as required to install the new transmission facilities. Failure to meet a scheduled facility outage may result in project delays.
- Excepting any operational, governmental, and/or environmental regulatory delays, the use of additional resources, such as overtime, premiums for expedited material, and/or contractor labor, may enable PPL EU to decrease this construction period but no guarantees can be made. It is also assumed that all ROW and easements are secured by the anticipated construction start dates.

8. Other Items for the Interconnection Customer

Alternate Outlet

The IC has not requested an alternate outlet for their generation. When the Harwood - E. Hazelton #2 69 kV line is removed from service for any line maintenance, repair activities, or if the main line needs to be upgraded, the generator will be required to come off line. Some of these activities may require the line to be out of service for extended durations. With no alternate outlet, this customer will not be able to generate for this duration.

Maintenance Considerations

The Z2-009 IC will not be able to generate into the PPL EU network during maintenance on the new 69 kV generator supply line or the main Harwood-East Hazleton #2 69 kV line. PPL EU on-going annual and long-term planned maintenance of this circuit will require PPL EU to remove the circuit from operation one (1) time every four (4) years, for an outage period of approximately two (2) weeks. During maintenance periods, the circuit may or may not be returned to service during the evening hours. That decision depends on the type of work being performed. Unexpected and unplanned maintenance outages are not included in the one-in-four number and duration time. Annual inspections that uncover damaged poles, conductors, or hardware, which require immediate repair, are scheduled as soon as practicable. These types of unplanned outages may last up to 16 hours.

Z2-009 Generator, GSU, and Line Modeling

The Interconnection Customer will be responsible for the construction of all their generating station facilities on the Interconnection Customer side of the POI (Point of Interconnection).

<u>Z2-009 Generator modeling</u>
Number of Turbines: 19 (Alstom ECO 122)
Size: 2.7 MW per turbine
MVA Base: 3.27 MVA
0.90 lead to 0.90 lag power factor at the 69 kV bus

Z2-009 GSU modeling
GSU (Generator Step Up Transformer):

- Number of machines per GSU: 19
- MVA Base: 45 MVA
- Voltage Level: 34.5/69 kV
- Impedance: 8.0%

GSU (Wind Turbine Unit):

- MVA Base: 3.2 kV
- Voltage Level: 34.5/0.69 kV

Z2-009 Transmission Line modeling

- Voltage Level: 69 kV
- MVA Base: 100 MVA
- Length: 0.1 miles
- Positive sequence impedance: 0.0004+j0.0015
- Negative sequence impedance: 0.0004+j0.0015

The Z2-009 Interconnection Customer must provide PPL EU and PJM with the transformer test reports once they are available in order to perform a more detailed short circuit analysis.

Intertie and POC Protective Relaying Equipment

The Interconnection Customer will need to install suitable protection and control equipment at its facilities based on PPL EU parallel generation requirements. This includes both Intertie Protective Relaying (IPR) and Point of Contact (POC) relaying. Please refer to the PPL EU web site for the IPR and POC requirements. The website addresses are shown below:

IPR Requirements:
https://www.pplelectric.com/at-your-service/electric-rates-and-rules/customer-owned-generation.aspx

POC Requirements:
https://www.pplelectric.com/at-your-service/electric-rates-and-rules/point-of-contact-requirements-for-high-voltage-facilities.aspx

Isolation Breaker Requirement at the Interconnection Customer's Substation

Per the customer's preliminary sketches, the customer is planning to provide a high side circuit breaker at 69 kV with a manually operated 69 kV disconnect switch on the PPL EU line side of this breaker. Unless otherwise indicated, it is assumed that this will be the "Isolation Circuit Breaker" and will be operated by the IPR relay and the DTT signal. It is requested that the customer confirm this or provide alternate isolation breaker.

Z2-009 Generator Harmonic and Flicker Requirements

On the PPL EU 69 kV system, the total harmonic distortion to the fundamental voltage wave from a single customer is limited to 1.5% of nominal. In addition, no individual harmonic component can exceed 1.0% of the fundamental system voltage.

If PPL EU discovers that objectionable harmonics in excess of the stated limits are being injected into the system from Z2-009's equipment, the Queue Z2-009 Interconnection Customer will be responsible for taking corrective measures to mitigate harmonic currents.

Concerning voltage flicker, the Interconnection Customer must limit the severity of their voltage variation to within a level which will not cause objectionable flickers to other customers. A voltage drop greater than 5% at the point of interconnection is not acceptable. The frequency and severity of the voltage variation will be considered when determining whether a customer's equipment is violating PPL EU flicker guidelines. PPL EU uses the General Electric flicker-irritation curves as a guideline to determine if the system is operating within acceptable limits. PPL EU will require corrective actions by the Interconnection Customer if their operation causes flickers that exceed PPL EU guidelines. One such correction could be the installation of static var compensators (SVC) to hold a constant voltage.

Z2-009 Generator Regulation or Reactive Support Requirements

As specified in Section 4.7.1.1 of the PJM OATT (Open Access Transmission Tariff), the Z2-009 Project shall design its Facility to meet the following power factor requirement:

"For all new wind-powered and other non-synchronous generation facilities, if determined in the system Feasibility study to be required for the safety or reliability of the Transmission System, the Generation Interconnection Customer shall design its Customer Facility with the ability to maintain a composite power delivery at continuous rated power output at a power factor of at least 0.95 leading (absorbing vars) to 0.95 lagging (supplying vars)."

The IC will be required to hold voltage constant at the point of interconnection to the PPL EU 69 kV system. PPL EU will provide a MW-MVAR schedule to achieve this constant voltage after signing the IC signs the ISA/ICSA.

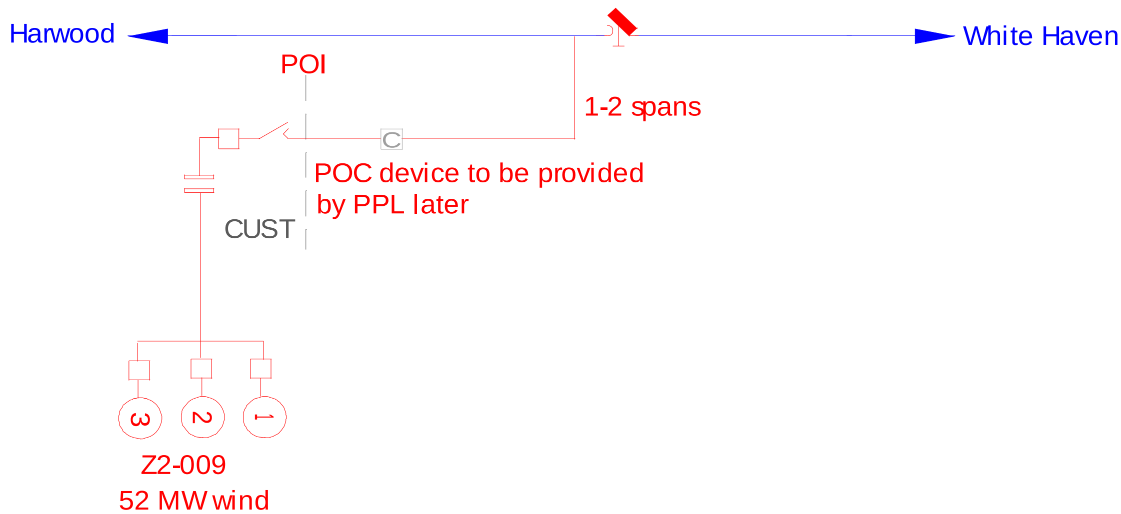
Distribution Service Requirements

The Interconnection Customer must submit a request for electric service through PPL EU"s Industrial and Commercial Services (ICS) group if the queue Z2-009 requires back-up electric service at a voltage less than 69 kV. The ICS Help Desk can be reached at 1-888-220-9991. Cost for distribution electric service is NOT included in the PPL scope of work transmission or substation estimates.

Future Conversion of line to 138 kV from 69 kV

PPL EU presently has no plans to convert this line to 138 kV in the next 15-20 years. If the transmission system in this area is converted to 138 kV in the future, the Interconnection Customer would be responsible for conversion of its substation to 138kV at that time.

Attachment 1. Single Line Diagram



Attachment 2. Stability Study Analysis

Executive Summary

PJM Queue project Z2-009 is a request for a 52.0 MW MFO injection to Harwood – East Hazelton 69 kV circuit # 2 in the PPL 69 kV transmission system. Z2-009 project consists of 26 Vestas-110, 2.2 MW Wind Turbines.

This study is based on the RTEP 2018 summer peak load case and RTEP 2018 light load case. Both cases were modified to include applicable queue projects. For summer peak case, PJM queue project Z2-009 was dispatched at a maximum power transfer of 52.0 MW and POI voltage of 66.8 kV, consistent with the default generator reference voltage specified in PJM Manual 03 Transmission Operations Section 3.3.3 for generator connections to the PJM 69.0 kV system. For light load case, queue project Z2-009 was dispatched at a maximum power transfer of 52.0 MW and POI voltage of 67.0 kV

Z2-009 was tested for compliance with NERC, PJM and other applicable criteria. 30 contingencies were studied for both summer peak and light load cases, each with a 15 second simulation time period.

Based on the contingencies tested, Z2-009 meets criteria for all the contingencies tested.

Note: The contingencies results show some prolonged power oscillations that clearly decay over about 30 seconds. The impact of connection point on these oscillations were further investigated by moving the POI at 69 kV Harwood and 230 kV Harwood TS and tested 3phase fault on Harwood 69/230 kV TR4. The same type of oscillations were observed in all these investigations and testing. The same contingencies also were tested using un-stressed case with same results. It was concluded that the oscillations are not related to the POI but are due to machine dynamic models controls.

A 3 phase fault on 69/230 kV Harwood TR4 using stressed case and simulation time of 30 seconds run time showed all oscillations damped out completely. A further study will be required once another model is available but at this time no mitigation is required.

Description

This study evaluates the stability and dynamics for PJM queue project Z2-009 that is a connection at Harwood 69 kV substation in the PPL territory via Harwood – East Hazelton 69 kV circuit 2. The Z2-009 project is a wind turbine facility unit made up of 26 Vestas 110 2.0 MW wind turbines. The wind turbines facility is modeled at 52.0 MW gross output. For this stability study, the Z2-009 project was studied as a total net injection of 51.0 MW into the 69.0 kV Transmission System.

Criteria

The stability study for Z2-009 was performed on a RTEP 2018 Summer Peak load case for normal operating conditions, and modified to include applicable queue projects. The study was repeated using RTEP 2018 light load case. 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-001faults include:

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

Note: For generator interconnection studies, Category P2, P3 and P6 faults will be studied on an as needed basis.

Other applicable criteria tested include:

1. TO specific criteria
2. Other criteria

The system was tested for an 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.

Case Setup

Generators within 5 to 8 buses from the generator(s) under study are dispatched at their maximum power output and set at unity power factor at the high side of the generator step up transformer. Alternatively, generators can be adjusted to hold scheduled voltages.

Specific dispatch conditions at the generator terminals for the Z2-009 generator, as obtained in the power flow solution, are illustrated below:

	26 Vestas 110 2.0 MW Wind Turbines
Gross power output (MW)	52.0
Reactive power output (MVARS)	4.5
Auxiliary Load (MW/MVARS)	0.5, 0.7
Station Service Load (MW/MVARS)	
Net real power injection (MW)	51.0
Voltage at the POI (P.U.)	0.97

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 32.0, the 2018 case with a Summer Peak Load condition and the data supplied by the developer.

Transient Stability

For all cases studied, 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.

LVRT

For the cases studied, the queue project rides through the faults shown in Appendix A thus meeting the LVRT test specified in FERC order 661 and 661A.

Note: The contingencies results show some prolonged power oscillations that clearly decay over about 30 seconds. The impact of connection point on these oscillations were further investigated by moving the POI at 69 kV Harwood and 230 kV Harwood TS and tested 3phase fault on Harwood 69/230 kV TR4. The same type of oscillations were observed in all these investigations and testing. The same contingencies also were tested using un-stressed case with same results. It was concluded that the oscillations are not related to the POI but are due to machine dynamic models controls.

A 3 phase fault on 69/230 kV Harwood TR4 using stressed case and simulation time of 30 seconds run time showed all oscillations damped out completely. A further study will be required once another model is available but at this time no mitigation is required.

Maintenance outage

No maintenance outage conditions were evaluated.

Conclusion

No issues were identified for the stability study performed for PJM queue project Z2-009.

Mitigations:

None required.

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.

Appendix A: Fault Table

No.	Contingency ID	Type of Fault	Clearing time (cycles)		Results
			Normal	Delayed	
TPL 001-4_P1					
1	Z2-009-P1-HAR01	3ph fault on Harwood - Hum b#1 69 kV	12.0	N/A	Stable
2	Z2-009-P1-HAR02	3ph fault on Harwood - Hum b#2 69 kV	12.0	N/A	Stable
3	Z2-009-P1-HAR03	3ph fault on Harwood – Valmont #2 69 kV	12.0	N/A	Stable
4	Z2-009-P1-HAR04	3ph fault on Harwood – Berwick 69 kV	12.0	N/A	Stable
5	Z2-009-P1-HAR05	3ph fault on Harwood – Valmont #1 69 kV	12.0	N/A	Stable
6	Z2-009-P1-HAR06	3ph fault Harwood – JENK 69 kV	12.0	N/A	Stable
7	Z2-009-P1-HAR07	3ph fault Harwood 69/230 kV TR5	12.0	N/A	Stable
8	Z2-009-P1-HAR08	3ph fault Harwood 69/230 kV TR6	12.0	N/A	Stable
9	Z2-009-P1-HAR09	3ph fault Harwood 69/230 kV TR4	12.0	N/A	Stable
10	Z2-009-P1-HAR10	3 ph fault on Harwood – Susquehanna 230 kV ckt 1	8.0	N/A	Stable
11	Z2-009-P1-HAR11	3 ph fault on Harwood – Palmerton 230 kV	8.0	N/A	Stable
12	Z2-009-P1-HAR12	3 ph fault on Harwood – Susquehanna 230 kV ckt 2	8.0	N/A	Stable
13	Z2-009-P1-HAR13	3 ph fault on Harwood – Siiegfried 230 kV	8.0	N/A	Stable
14	Z2-009-P1-HAR14	3 ph fault on Mountain 69/230 kV TR	12.0	N/A	Stable
15	Z2-009-P1-HAR01	3ph fault on Harwood – Hazelton East#1 69 kV	12.0	N/A	Stable
TPL 001-4_P4					
16	Z2-009-P4-HAR-01	SLG fault on Harwood 69/230 kV TR5, SB @ Harwood 69 kV, Loss of Harwood – Valmont #2 69 kV + Harwood - Hum b#2 69 kV + on Harwood – Hazelton East#1 69 kV	12.0	60.0	Stable
17	Z2-009-P4-HAR-02	SLG fault on Harwood 69/230 kV TR6, SB @ Harwood 69 kV, Loss of Harwood - Hum b#1 69 kV, Harwood Yard Span	12.0	60.0	Stable
18	Z2-009-P4-HAR-03	SLG fault on Harwood 69/230 kV TR4, SB @ Harwood 69 kV, Loss of Harwood S bus	12.0	60.0	Stable
19	Z2-009-P4-HAR-04	SLG fault on Harwood – Valmont #1 69 kV, SB @ Harwood 69 kV, Loss of Harwood Yard Span	12.0	60.0	Stable
20	Z2-009-P4-HAR-05	SLG fault on Harwood – JENK1 69 kV, SB @ Harwood 69 kV, Loss of Harwood - Hum b#2 69 kV	12.0	60.0	Stable
21	Z2-009-P4-HAR-06	SLG fault on Harwood - Hum b#2 69 kV, SB @ Harwood 69 kV, Loss of Harwood – JENK1 69 kV	12.0	60.0	Stable
22	Z2-009-P4-HAR-07	SLG fault on Harwood – Valmont #1 69 kV, SB @ Harwood 69 kV, Loss of Harwood Yard Span	12.0	60.0	Stable
22	Z2-009-P4-HAR-08	SLG fault on Harwood - Berwick 69 kV, SB @ Harwood 69 kV, Loss of Harwood 69/230 kV TR5 + Harwood – Valmont #2 69 kV + Harwood – Hazelton East#1 69 kV	12.0	60.0	Stable
24	Z2-009-P4-HAR-09	SLG fault on Harwood 230/69 kV TR5 + Harwood – Susquehanna 230 kV ckt 1, SB @ Harwood 230 kV, Loss of Harwood – Siiegfried 230 kV	8.0	17.0	Stable
25	Z2-009-P4-HAR-10	SLG fault on Harwood – Siiegfried 230 kV, SB @ Harwood 230 kV, Loss of Harwood 230/69 kV TR5 + Harwood – Susquehanna 230 kV ckt 1	8.0	17.0	Stable
26	Z2-009-P4-HAR-11	SLG fault on Harwood 230/69 kV TR4 + Harwood – Susquehanna 230 kV ckt 2, SB @ Harwood 230 kV, Loss of Harwood –	8.0	17.0	Stable

No.	Contingency ID	Type of Fault	Clearing time (cycles)		Results
		Siiegfried 230 kV			
27	Z2-009-P4-HAR-12	SLG fault on Harwood – Susquehanna 230 kV ckt 1 + Harwood 230/69 kV TR5, SB @ Harwood 230 kV, Loss of Harwood 230/69 kV Tr 6 + Harwood – Palmerton 230 kV	8.0	17.0	Stable
28	Z2-009-P4-HAR-13	SLG fault on Harwood 230/69 kV TR 6 + Harwood – Palmerton 230 kV, SB @ Harwood 230 kV, Loss of Harwood 230/69 kV TR4 + Harwood – Susquehanna 230 kV ckt 2	8.0	17.0	Stable
29	Z2-009-P4-HAR-14	SLG fault on Harwood 230/69 kV Tr 6 + Harwood – Palmerton 230 kV, SB @ Harwood 230 kV, Loss of Harwood 230/69 kV TR5 + Harwood – Susquehanna 230 kV ckt 1	17.0		Stable
TPL 001-4_P7					
30	Z2-009-P47HAR-01	SLG fault on Harwood - Hum b#1 69 kV & Harwood – Berwick 69 kV & Harwood – JENK 69 kV	12.0	N/A	Stable

Appendix B: Project Model

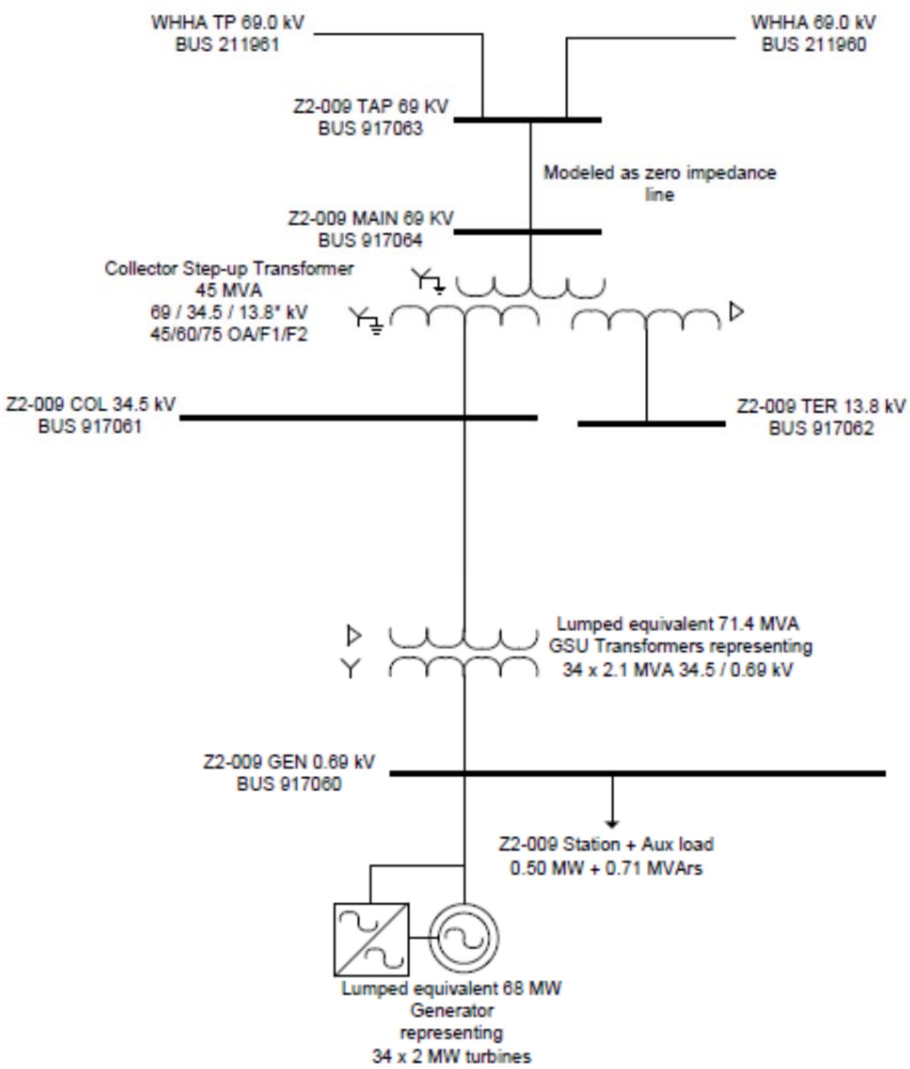


Figure 1: Z2-009 Plant Model

Figure B-1: PJM Z2-009 modeling details

Appendix C: Power Flow and Dynamic Models

C.1) PSS/E Models

Vestas 110 2.0 MW Wind Turbine Model

C.2) Power Flow Model Data

```
RDCH
1,   100.00, 32, 0, 1, 60.00     / PSS®E-32.2    TUE, MAR 03 2015  17:04
2012 SERIES, ERAG/MMWG BASE CASE LIBRARY
2018 SUMMER PEAK LOAD CASE, FINAL; FOR DYN
917060,'Z2-009 GEN  ',   0.6900,2, 229, 239,   1,0.97557, -12.6927
917061,'Z2-009 COL  ',  34.5000,1, 229, 239,   1,0.96682, -17.0133
917062,'Z2-009 TER  ',  13.8000,1, 229, 239,   1,0.96536, -16.6640
917063,'Z2-009 TAP  ',  69.0000,1, 229, 239,   2,0.96862, -22.5818
917064,'Z2-009 MAIN ',  69.0000,1,   1,   1,   1,0.96862, -22.5818
0 / END OF BUS DATA, BEGIN LOAD DATA
917060,'1 ',1,   1,   1,     0.500,     0.710,     0.000,     0.000,     0.000,     0.000,
1,1
0 / END OF LOAD DATA, BEGIN FIXED SHUNT DATA
0 / END OF FIXED SHUNT DATA, BEGIN GENERATOR DATA
917060,'1 ',    52.000,     4.510,     4.510,    -4.510,1.00000,     0,    54.080, 5.00000E-3,
1.99100E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,    52.000,     0.000,   1,1.0000
0 / END OF GENERATOR DATA, BEGIN BRANCH DATA
211960,917063,'1 ', 2.03000E-2, 8.29500E-2,   0.00140,   97.00,  124.00,    0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   5.18,   2,1.0000
211961,917063,'1 ', 2.03000E-2, 8.29500E-2,   0.00140,   97.00,  124.00,    0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,2,   5.18,   2,1.0000
917063,917064,'1 ', 0.00000E+0, 1.00000E-4,   0.00000,    0.00,    0.00,    0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
0 / END OF BRANCH DATA, BEGIN TRANSFORMER DATA
917061,917060,     0,'1 ',1,2,1, 0.00000E+0, 0.00000E+0,2,'            ',1,   1,1.0000
 6.30000E-3, 7.58000E-2,    54.60
1.00000,   0.000,   0.000,    54.60,     0.00,     0.00, 0,      0, 1.05000, 0.95000, 1.10000,
0.90000,   5, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
917064,917061,917062,'1 ',1,2,1, 0.00000E+0, 0.00000E+0,2,'            ',1,   2,1.0000
 2.50000E-3, 7.99000E-2,    45.00, 2.50000E-3, 3.21200E-2,    45.00, 2.50000E-3, 1.22030E-1,
45.00,0.96536, -16.6640
1.00000,   0.000,   0.000,   45.00,    60.00,    75.00, 0,      0, 1.05000, 0.95000, 1.10000,
0.90000,   5, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000,   0.000,   45.00,    60.00,    75.00, 0,      0, 1.05000, 0.95000, 1.10000,
0.90000,   5, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000,   0.000,   45.00,    60.00,    75.00, 0,      0, 1.05000, 0.95000, 1.10000,
0.90000,   5, 0, 0.00000, 0.00000,  0.000
0 / END OF TRANSFORMER DATA, BEGIN AREA DATA
 229,     0,     0.000,     0.000,'PL          '
0 / END OF AREA DATA, BEGIN TWO-TERMINAL DC DATA
0 / END OF TWO-TERMINAL DC DATA, BEGIN VSC DC LINE DATA
0 / END OF VSC DC LINE DATA, BEGIN IMPEDANCE CORRECTION DATA
0 / END OF IMPEDANCE CORRECTION DATA, BEGIN MULTI-TERMINAL DC DATA
0 / END OF MULTI-TERMINAL DC DATA, BEGIN MULTI-SECTION LINE DATA
0 / END OF MULTI-SECTION LINE DATA, BEGIN ZONE DATA
   1,'CHICAGO     '
 239,'CENTRAL     '
0 / END OF FACTS DEVICE DATA, BEGIN SWITCHED SHUNT DATA
0 / END OF SWITCHED SHUNT DATA, BEGIN GNE DATA
0 / END OF GNE DATA
Q
```

C.3) Dynamic Data

```
/ **********************************
/ *** Z2-009 - 67.5 MW          ***
/ **********************************

917060 'USRMDL' '1 '  'VWCOR6' 1 1 2 45 23 104 1 0
 2000.0000 690.0000 903.3041 700.0000 2.6200 0.9676 0.0232
 1.9807 8.3333 1.9807 8.3333 30.0000 0.2000 1.2000
 0.1000 0.0012 0.9925 0.0474 1.6118 0.0000 351.8584
 161.5343 0.0300 0.0000 0.0300 0.3000 0.0000 1.0000
 0.3183 4.9736 2812227.1900 43.2960 90.0120 600000.0000 3.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000/
0 'USRMDL' 0 'VWVAR6' 8 0 2 0 0 30 917060 '1 '  /
0 'USRMDL' 0 'VWLVR6' 8 0 3 65 10 35 917060 '1 ' 1
 0.9000 0.0010 0.1500 18.6316 74.5430 74.5430 74.5430
 0.5000 1.0000 2.6200 0.9676 1.2000 0.5000 690.0000
 903.3041 0.3500 0.0500 0.2500 0.0200 3.0000 4.0000
 9999.0000 0.0232 0.9000 0.9000 0.0500 0.0000 0.0100
 0.0000 2.0000 0.0000 1.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 /
0 'USRMDL' 0 'VWPWR6' 8 0 3 30 7 10 917060 '1 ' 1
 1.0000 0.5000 -0.5000 0.6988 0.8844 0.9800 0.9600
 0.2000 0.2000 1.0000 1.0000 0.0000 0.0000 0.1000
 0.1000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 /
0 'USRMDL' 0 'VWMEC6' 8 0 2 10 8 0 917060 '1 '
 2000.0000 422.2301 4736.7543 420.7500 83.5000 6188.8071 39.3992
 0.0000 0.0000 0.0000 /
0 'USRMDL' 0 'VWMEA6' 8 0 2 10 8 5 917060 '1 '
 0.1000 0.1000 0.1000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000/
0 'USRMDL' 0 'VWVPR6' 0 2 7 30 0 18 917060 '1 '  1 1 0 0 0
 0.8500 11.0000 0.8500 11.0000 0.9000 60.0000 1.1000
 60.0000 1.1500 2.0000 1.2000 0.0800 1.2500 0.0050
 1.2500 0.0050 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.1500 0.8000 2.7000 0.8500 3.5000
 0.9000 5.0000 /
0 'USRMDL' 0 'VWFPR6' 0 2 3 12 0 7 917060 '1 '  0
 56.4000 0.2000 56.4000 0.2000 56.4000 0.2000 63.6000
 0.2000 63.6000 0.2000 63.6000 0.2000 /
```

C.4) PSS/E Single Line Diagram

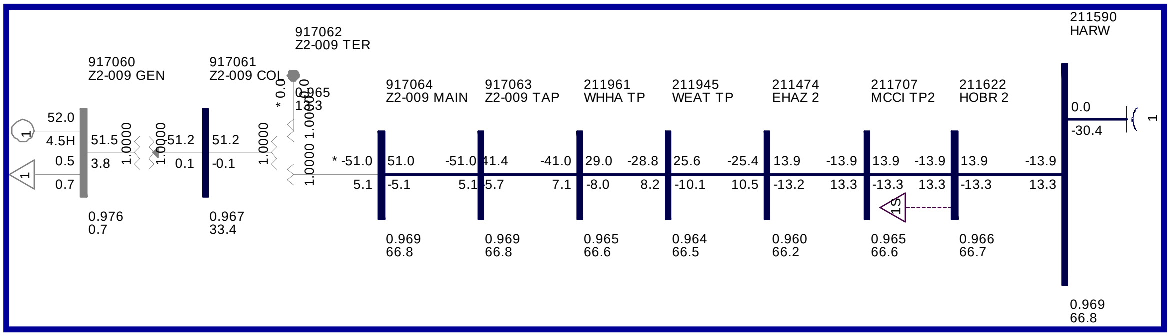


Figure C-1: Single-line diagram for Z2-009 2018-SP case (Breaker information not shown)

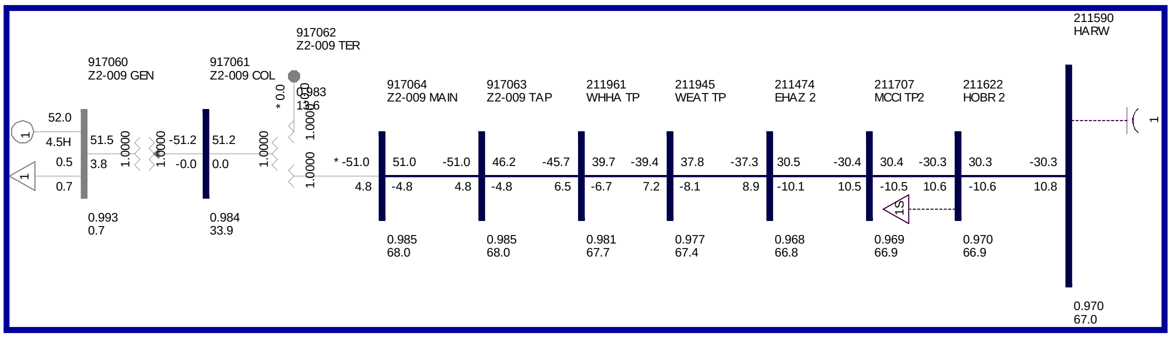


Figure C-2: Single-line diagram for Z2-009 2018-LL case (Breaker information not shown)