PJM Generator Interconnection Request
Queue AA1-128
Glen Lyn 34.5 kV
Feasibility/Impact Study Report

June 2015

Preface

The intent of the Feasibility/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 Feasibility/System Impact Study is performed.

The Feasibility/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.

This report is divided into two sections:

Part I – AEP Distribution Planning Analysis and Results
Part II – Transmission Planning Analysis and Results

© PJM Interconnection 2015. All rights reserved.

Part I - AEP Distribution Planning Analysis and Results

Request

Appalachian Power Company, 1 Riverside Plaza, Columbus, Ohio 43215 (Generator), as an Interconnection Customer (IC) of the PJM regional transmission operator (RTO), submitted an interconnection request to connect a battery-powered distributed generation (DG) facility capable of 10.0 MW maximum output power to AEP APCo distribution facilities.

Disclaimer

The contents of this feasibility/impact study apply only to the facility described in the attached Distributed Generation (DG) Interconnection Request application. All modeling is based on the Point of Common Coupling (PCC) at AEP APCo primary meter location to be established located at 100 APCo Road, Glen Lyn, VA 24093.

Modeling and Assumptions

The Generator consists of 5 installations of the following; one 2 MW battery connected to an Eaton Power Expert 2000 inverter. The output of the inverter will connect to a 2500kVA, 480V(Y) – 34.5 kV(Y), Z = 5.75%, step-up transformer. The output of the five customer owned transformers will tie to a common bus and through the customer owned protective breaker, connect to the PCC, which connects to a new 34.5 kV circuit breaker connected to the Glen Lyn 34.5 kV bus.

The Generator will be served from Glen Lyn Station, 34.5 kV bus, a radial configuration, three-phase multi-grounded four-wire wye system. The 34.5 kV bus is served from XF#9, a 138 kV(GY) – 34.5 kV(Δ) 30 MVA transformer. The 34.5 kV winding of this transformer is grounded through GND XF#7. Nominal frequency is 60 Hertz.

The Generator intends to participate at 10 MW in the ancillary services schedule 2 and schedule 3 PJM wholesale marketplace. The output of the DG is varied based upon the Dynamic Regulation signal from PJM. This signal ranges from a value of 1.0 representing maximum battery output, to a value of -1.0 representing maximum battery charging. This signal is delivered to the DG in two second intervals. While it is most common for this signal to increase and decrease by small increments, historical analysis of this signal indicates that the fluctuations can be much more extreme. For this study, a transition from maximum output (1.0) to maximum charge (-1.0) and maximum charge to maximum output was thoroughly analyzed in the *System Voltage Levels* portion of this study.

The generator requires 10.0 MW during their charging periods. The inverters will operate at or very near unity power factor. The maximum fault current contribution of the inverters, as a percentage of full load current, is 115%. The Eaton Power Expert 2000 inverter is not UL1741-2005 listed. The customer will have to test the DG system per IEEE 1547.1 unless documented proof of UL1741 – 2005 certification is provided to AEP prior to commissioning.

AEP Fault Values and Thevenin Impedances

The following are AEP symmetrical fault values and AEP Thevenin impedances calculated at the Generator PCC without DG facility connected. The nominal voltage can vary +/- 5%.

Glen Lyn 34.5 kV bus (PCC)

- LLL = 4134 A LG = 5766 A
- Z1 = 0.3115 + j 4.8084 ohms
- Z2 = 0.3097 + j 4.8015 ohms
- Z0 = 0.0702 + j 0.7298 ohms

© PJM Interconnection 2015. All rights reserved.

Analysis

Cymdist Version 7.1r02 was utilized to model the DG effects on the following:

System Load Flows
System Voltage Levels
System Fault Levels and Overcurrent Protection

System Load Flows

The system model indicates that no AEP equipment will experience conditions exceeding equipment rating due to the Generator operating under peak load, light load, or abnormal operating conditions.

<u>Generator Charging</u>
The Generator charging at full 10 MW capacity during summer or winter peak loading condition produces an XF#9 load 5 MVA below its seasonal capability, regardless of the season.

<u>Generator Discharging</u>
Assuming the Generator exporting all of its capacity into Glen Lyn 34.5 kV bus during peak loading condition produces 10 MW flowing into the area electric power system (EPS) through the PCC. The capacity will be used by the three 34.5 kV circuits connected to the 34.5 kV station bus.

Assuming the Generator exporting all of its capacity into Glen Lyn 34.5 kV bus during summer light loading with first contingency condition of circuit breaker AB (Glen Lyn-Peterstown circuit) open produces 10 MW flowing into the area electric power system (EPS) through the PCC and new distribution circuit breaker (see simplified one line below). Roughly 7400 kW will backflow through the 34.5 kV XF#9 low side transformer breaker (breaker AF) at the Glen Lyn station through XF#9 into the 138 kV system. The backflow into the new distribution circuit breaker and the 34.5 kV XF#9 circuit breaker caused by the DG will require a re-coordination study for AEP protective circuit device settings. The Generator's main protective device will need to be coordinated with the new distribution circuit breaker and the 34.5 kV XF#9 circuit breaker circuit breaker settings.

System Voltage Levels

Circuit studies were conducted at both peak loading and light loading conditions. With the Glen Lyn circuits modeled at peak loading conditions and the Generator at maximum output (10.0 MW total). A transient stability study was created with the Generator transitioning from full discharge to full charge (a 20 MW swing) over 2 seconds. An additional transient stability study was created with the Generator transitioning from full charge to full discharge (a 20 MW swing) over 2 seconds. This entire process was repeated with the circuit modeled at light loading conditions.

Generator modeling on the Glen Lyn station circuit indicates that the transition from maximum charging load to maximum output causes an increase in system voltage of 1.34% at the customer PCC, 1.34% at the Glen Lyn station 34. 5 kV bus, and 1.76% at the Pearisburg station 12 kV bus. These transient voltage fluctuations will be perceived by other customers on the AEP distribution system.

System Fault Levels and Overcurrent Protection

The addition of this DG equipment will subject AEP overcurrent protection devices to increased fault current. These increases, measured at the PCC, are outlined as follows:

- With no DG equipment connected:
  - LLL = 4134 A LG = 5766 A
- With DG equipment connected:
  - LLL = 4355 A LG = 5906 A

The fault contribution increase caused by the DG will require a re-coordination study for AEP protective circuit devices. Additionally, the Generator's main protective device will need to be coordinated with the

© PJM Interconnection 2015. All rights reserved.

new distribution circuit breaker (see simplified one line below) control settings. As per the primary metering guidelines, the generator shall include a loss of phase protection scheme.

Transmission P&C will perform any reset of the 34.5 kV XF#9 low side transformer breaker (breaker AF) and new circuit breaker necessary to coordinate with the Generator to allow itself to isolate during an outage condition.

System Protection

The Generator responsibilities include providing adequate protection to AEP facilities due to events arising from the operation of the Generator under all AEP distribution system and Generator operating conditions. The Generator is responsible for protecting their own facility under all AEP distribution system operating conditions whether the Generator is connected to AEP facilities or not including but not limited to:

1. Abnormal voltage or frequency
2. Loss of a single phase of supply
3. Equipment failure
4. Distribution system faults
5. Lightning
6. Excessive harmonic voltages
7. Excessive negative sequence voltages
8. Separation from supply
9. Loss of synchronization

IEEE Standard 1547-2003 “Standard for Interconnecting Distributed Resources with Electric Power Systems” is the basis for interconnection technical requirements for system protection.
The interconnection system hardware and software used by a Distributed Resource to meet the technical requirements do not have to be located at the Point of Common Coupling. However, the technical requirements shall be met at the Point of Common Coupling. For additional information on interconnection technical requirements please refer to the AEP Interconnection Guide and IEEE 1547-2003.

The cost of any damage resulting from a system condition caused by the installation and/or operation of the DG will be borne by the owner of the DG facility.

Abnormal distribution system events will be addressed on an individual basis through the AEP system operator. Corrective action shall be based on the judgment of the AEP system operator. Possible corrective action can include but is not limited to DG isolation from the distribution system.

This review has been limited to items which may affect the AEP system or to suggestions which may improve operations. The Generator must take all necessary steps to assure compliance with all laws, ordinances, building codes and other applicable regulations. Approval of this connection by AEP, when granted, is not an endorsement of a particular design nor does it assure fitness to accomplish an intended function.

Any additional AEP work to mitigate power quality issues not foreseen by this study but associated with the interconnection will be at the sole cost and expense of the Generator.

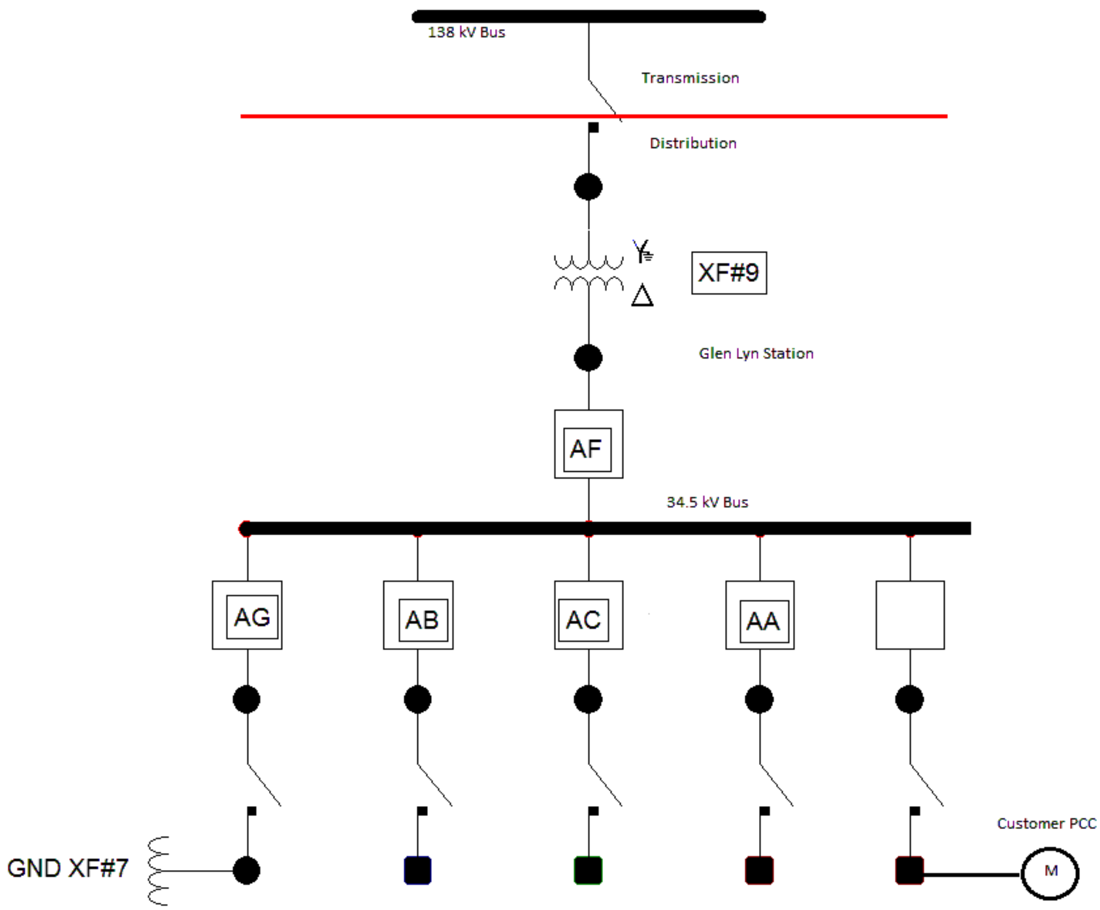
© PJM Interconnection 2015. All rights reserved.

Summary

AEP System Improvements for Interconnection

N/A

Simplified One-Line Diagram



The above simplified one-line is the model "as studied" and does not include suggested mitigation.

Assuming an abnormal condition of the Generator exporting all of its capacity into Glen Lyn 34.5 kV bus during summer light loading with first contingency condition of circuit breaker AB (Glen Lyn-Peterstown circuit) produces 10 MW flowing into the area electric power system (EPS) through the PCC. Roughly 7384 kW will backflow through the 34.5 kV XF#9 circuit breaker (breaker AF) at the Glen Lyn station through XF#9 into the 138 kV system. The backflow into the new distribution circuit breaker and the 34.5 kV XF#9 circuit breaker caused by the DG will require a re-coordination study for AEP protective circuit device settings. The Generator's main protective device will need to be coordinated with the new distribution circuit breaker and the 34.5 kV XF#9 circuit breaker circuit breaker settings.

Generator modeling on the Glen Lyn station circuit indicates that the transition from maximum charging load to maximum output causes an increase in system voltage of 1.34% at the customer PCC, 1.34% at the Glen Lyn station 34. 5 kV bus, and 1.76% at the Pearisburg station 12 kV bus. These transient voltage fluctuations will be perceived by other customers on the AEP distribution system.

© PJM Interconnection 2015. All rights reserved.

Generator Requirements for Interconnection

The connection of the battery will cause transient voltage variation on AEP APCo distribution facilities unless distribution facilities are exclusively dedicated to the battery connection which is in conflict with AEP APCo electric service terms and conditions. The Battery must seek connection at transmission level voltage to assure system stability, security, and integrity.

Generator modeling on the Glen Lyn station circuit indicates that the transition from maximum charging load to maximum output causes an increase in system voltage of 1.34% at the customer PCC, 1.34% at the Glen Lyn station 34. 5 kV bus, and 1.76% at the Pearisburg station 12 kV bus. These transient voltage fluctuations will be perceived by other customers on the AEP distribution system. These proposed generator induced voltage fluctuations can only be mitigated with a separate station transformer/distribution bus facility to allow connection at the Glen Lyn station.

Cost to the Generator

As a convenience to the customer, a conceptual estimate for a dedicated substation to serve the battery facilities is approximately $3,800,000.00. Federal Gross-Up Tax, at the applicable rate, must be added to the total cost of the improvements.

Cost Estimate

N/A

Distribution Station

N/A

Total Estimated Cost

$3,800,000

© PJM Interconnection 2015. All rights reserved.

Part II – Transmission Planning Analysis and Results

Network Impacts

The Queue Project AA1-128 was studied as a 10.0 MW (Capacity 0.0 MW) injection at the Glen Lyn 34 kV substation in the AEP area. Project AA1-128 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AA1-128 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Summer Peak Analysis - 2018

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)

To be determined

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.

© PJM Interconnection 2015. All rights reserved.

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.

None

Light Load Analysis - 2018

Not required

System 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

Short Circuit

(Summary form of Cost allocation for breakers will be inserted here if any)

To be determined

Stability and Reactive Power Requirement

(Results of the dynamic studies should be inserted here)

Not required

© PJM Interconnection 2015. All rights reserved.