

***PJM Generator Interconnection Request
Queue AB2-010
Saltville-North Holston 34.5 kV
Feasibility/Impact Study Report***

August 2016

Preface

The intent of the feasibility study is to determine a plan, with ballpark cost and construction time estimates, to connect the subject generation to the PJM network at a location specified by the Interconnection Customer. The Interconnection Customer may request the interconnection of generation as a capacity resource or as an energy-only resource. As a requirement for interconnection, the Interconnection Customer may be responsible for the cost of constructing: (1) Direct Connections, which are new facilities and/or facilities upgrades needed to connect the generator to the PJM network, and (2) Network Upgrades, which are facility additions, or upgrades to existing facilities, that are needed to maintain the reliability of the PJM system.

In some instances a generator interconnection may not be responsible for 100% of the identified network upgrade cost because other transmission network uses, e.g. another generation interconnection, 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 impact study is performed.

The Feasibility 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

Appalachian Power Company has requested interconnection of a 5.0 MW (2.5 MW Capacity) solar generating facility in Smyth County Virginia.

The requested In Service date is: June 1, 2017

A test check out date for AB2-010 is projected to be approximately 4 weeks before the in service date listed above.

Attachment Facilities

Attachment Facilities and Appalachian Power Company's Distribution Analysis are described in Appendix 1 of this report. The Interconnection Customer will be required to enter into a construction agreement, and a Two Party Interconnection Agreement with AEP in order to construct the required attachment facilities.

Network Impacts

The Queue Project AB2-010 was evaluated as a 5.0 MW (Capacity 2.5 MW) injection at the Saltville 138kV substation in the AEP area. Project AB2-010 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AB2-010 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Summer Peak Analysis - 2020

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

Short Circuit

(Summary of impacted circuit breakers)

None

Affected System Analysis & Mitigation

None

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.

None

Light Load Analysis - 2020

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

System Reinforcements**Short Circuit**

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

None

Stability and Reactive Power Requirement

(Results of the dynamic studies should be inserted here)

To be determined

Summer Peak 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

Metering

(Revenue metering if to be owned and maintained by the TO - If TO does not wish to own metering please state this for customers information)

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 4 of PJM Manual 14D for additional information.

Appendix 1

**Distribution Feasibility Study
For Appalachian Power Company in Broadford, VA
Distributed Generation Interconnection Request AB2-010
5 MW Solar Facility**

Distribution System Planning
8/8/2016

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 solar-powered distributed generation (DG) facility capable of 5.0 MW maximum output power to AEP APCo distribution facilities.

Disclaimer

The contents of this feasibility 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 3456 Saltville Highway, Saltville, VA 24370.

Modeling and Assumptions

The Generator consists of separate installations in two different phases. AB2-010 represents Phase One of the combined installation. AB2-010 contains the following; one 5 MW solar array connected to six SMA Sunny Central 850CP-US inverters. The output of the inverters will connect to three 1700kVA, 34.5 kV(GY) - 386 V(Δ), $Z = 5.75\%$, step-up transformers. The output of the three customer owned transformers will tie to a common bus and through a customer owned protective breaker, connect to the PCC, which connects to a new 34.5 kV switch connected to the Saltville/North Holston 34.5 kV distribution circuit.

The Generator will be served from Saltville Station, 34.5 kV bus #2, a radial configuration, three-phase multi-grounded four-wire wye system. The 34.5 kV bus #2 is served from XF#2, a 138 kV(GY) – 34.5 kV(Δ) 20 MVA transformer. The 34.5 kV winding of this transformer is grounded through GND XF#4. Nominal frequency is 60 Hertz.

If scheduled maintenance is planned for Saltville XF#2, the 34.5 kV bus #2 will be switched and transferred to be served by Saltville XF#1, a 138 kV(GY) / 69 kV(GY) / 34.5 kV(Δ) 50/50/35 MVA three winding auto transformer. The 34.5 kV bus #2 is configured in such a way that the 34.5 kV winding of either Saltville XF#2 or XF#1 will be grounded through GND XF#4 regardless of which transformer is feeding into bus #2. Nominal frequency is 60 Hertz.

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 assumed to be 120%, based on research. The SMA Sunny Central 850CP-US inverter is UL1741 listed and IEEE 1547 compliant. The Generator is expected to understand and comply with IEEE 1547 concerning the DG installation and its requirements for interconnection with the distribution utility grid 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%.

Saltville/North Holston 34.5 kV Circuit From XF#2 (PCC)

- LLL = 1762 A LG = 1329 A
- $Z1 = 4.8024 + j 10.9417$ ohms
- $Z2 = 4.8024 + j 10.9417$ ohms
- $Z0 = 8.4062 + j 22.1293$ ohms

Saltville/North Holston 34.5 kV Circuit From XF#1 (PCC)

- LLL = 2583 A LG = 1579 A
- $Z1 = 4.5599 + j 6.6205$ ohms

- $Z2 = 4.5599 + j 6.6205$ ohms
- $Z0 = 8.3789 + j 22.1256$ ohms

Analysis

CYMDIST Version 7.2r04 was utilized to model the DG effects on the following:

1. System Load Flows
2. System Voltage Levels
3. 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.

Assuming the Generator exporting all of its capacity into the Saltville/North Holston 34.5 kV circuit during summer light loading with a first contingency condition of circuit breaker T (Saltville - Midway circuit) open produces 5 MW flowing into the area electric power system (EPS) through the PCC and the Saltville-North Holston circuit (see simplified one line below). Roughly 3600 kW will backflow through the 34.5 kV XF#2 low side transformer breaker (breaker N) at the Saltville station through XF#2 into the 138 kV system. The backflow into the 34.5 kV XF#2 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 Saltville-North Holston distribution circuit breaker (breaker O) and the 34.5 kV XF#2 circuit breaker (breaker N) settings.

System Voltage Levels

Circuit studies were conducted at both peak loading and light loading conditions. With the Saltville 34.5kV circuits modeled at peak loading conditions and the Generator at maximum output (5.0 MW total), a transient stability study was created with the Generator transitioning from sudden injection to sudden loss. This entire process was repeated with the Saltville 34.5 kV circuits modeled at light loading conditions. Light load conditions during summer at steady state was the only study conducted that produced results with circuit voltages exceeding the threshold of 126.0 volts (120 volt base).

Generator modeling on the Saltville station / North Holston circuit indicates that the transition from steady state without Generator output to the sudden injection of full Generator output causes an increase in system voltage of 2.7% at the customer PCC and 0.6% at the Saltville station 34.5 kV bus. Contrarily, Generator modeling on the Saltville station / North Holston circuit indicates that the transition from steady state with full Generator output to the sudden loss of full Generator output causes a decrease in system voltage of 2.9% at the customer PCC and 0.6% at the Saltville station 34.5 kV bus.

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 = 1762 A LG = 1329 A
- With DG equipment connected:
 - LLL = 1855 A LG = 1987 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 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.

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.

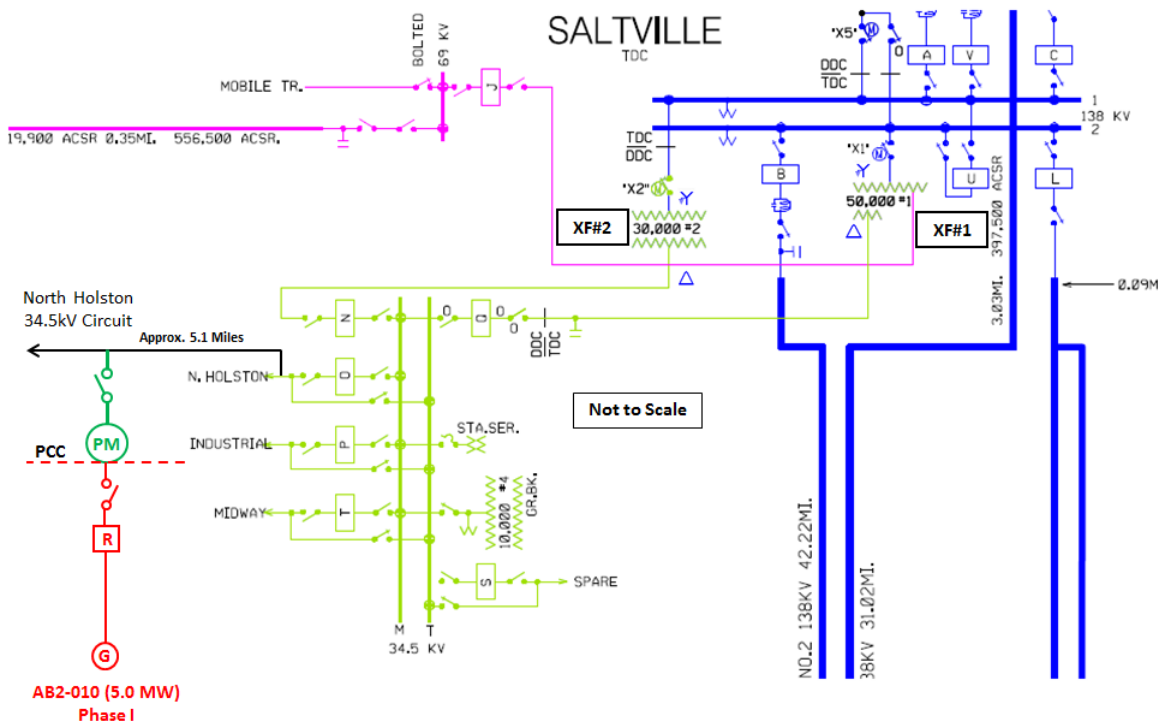
Any additional AEP work to mitigate power quality issues not foreseen by this study but associated with the interconnection will be at the sole cost and expense of the Generator.

Summary

AEP System Improvements for Interconnection

- Re-conductor 4.93 miles of three phase main line utilizing 4/0AA overhead conductor.
- Replace three voltage regulator controls with ones capable of co-generation mode.
- Install 34.5kV primary metering.
- Install SCADA communication for real-time monitoring of DG interconnection.

Simplified One-Line Diagram



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

Assuming the Generator exporting all of its capacity into the Saltville/North Holston 34.5 kV circuit during summer light loading with a first contingency condition of circuit breaker T (Saltville - Midway circuit) open produces 5 MW flowing into the area electric power system (EPS) through the PCC and the Saltville-North Holston circuit (see simplified one line above). Roughly 3600 kW will backflow through the 34.5 kV XF#2 low side transformer breaker (breaker N) at the Saltville station through XF#2 into the 138 kV system. The backflow into the 34.5 kV XF#2 transformer 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 Saltville-North Holston distribution circuit breaker (breaker O) and the 34.5 kV XF#2 circuit breaker (breaker N) settings. During contingency conditions the backflow into the 34.5 kV XF#1 transformer 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 34.5 kV XF#1 transformer breaker (breaker Q) settings.

Generator modeling on the Saltville station / North Holston circuit indicates that the transition from steady state without Generator output to the sudden injection of full Generator output causes an increase in system voltage of 2.7% at the customer PCC and 0.6% at the Saltville station 34.5 kV bus. Contrarily, Generator modeling on the Saltville station / North Holston circuit indicates that the transition from steady state with full Generator output to the sudden loss of full Generator output causes a decrease in system voltage of 2.9% at the customer PCC and 0.6% at the Saltville station 34.5 kV bus. These transient voltage fluctuations will not be perceived by other customers on the AEP distribution system.

Generator Requirements for Interconnection

The connection of the solar-powered generator will cause steady state and transient voltage variation on AEP APCo distribution facilities unless distribution facilities are upgraded to mitigate said variations. An option exists to connect at a 138 kV transmission level voltage from the AEP Broadford Station to assure enhanced system stability, security, and integrity.

Generator modeling on the Saltville station / North Holston circuit indicates that the transition from steady state without Generator output to the sudden injection of full Generator output causes an increase in system voltage of 2.7% at the customer PCC and 0.6% at the Saltville station 34.5 kV bus. Contrarily, Generator modeling on the Saltville station / North Holston circuit indicates that the transition from steady state with full Generator output to the sudden loss of full Generator output causes a decrease in system voltage of 2.9% at the customer PCC and 0.6% at the Saltville station 34.5 kV bus. These transient voltage fluctuations will not be perceived by other customers on the AEP distribution system.

Distribution Study Conclusion

The high level study did not reveal steady state loading issues and did not reveal any issues due to the additional fault current contribution of the generators. This does not mean however that issues will not be discovered during a more complete impact study. Light load conditions during summer at steady state was the only study conducted that produced results with circuit voltages exceeding the threshold of 126.0 volts (120 volt base). Although present during certain transient scenarios, voltage fluctuations fall below visibility curves and will not be perceived by other customers on the AEP distribution system.

Conceptual Costs for Interconnection

As a convenience to the customer, a conceptual estimate for upgrades on the Saltville-North Holston 34.5 kV distribution circuit is approximately \$920,000. Federal Gross-Up Tax, at the applicable rate, must be added to the total cost of the improvements. The presumption is that AEP will perform all distribution line upgrades including the installation of a primary metering structure and the related facilities to permit interconnection.

The installation of 34.5 kV metering at the interconnection point with the facility will cost approximately **\$30,000**. The cost of the SCADA communication connection will cost approximately **\$40,000**. The cost of all distribution line upgrades will cost approximately **\$845,000**. The cost of engineering time for coordination studies and field P&C time to perform any proposed breaker/device settings changes will cost approximately **\$5,000**.

Total estimated cost is **\$ 920,000** based on this high level analysis. When detailed engineering is performed the costs could be determined to be higher or lower. Also, an impact study may reveal additional work necessary to AEP facilities in order to permit interconnection.

Timetable for Construction

Total time to complete this project is approximately 8 months from the time that all required signed agreements are received. This time estimate is based upon the known work that is required as a result of this study. Additional work that might be indicated by an impact study would likely alter the required construction time.