PJM Generator Interconnection Request
Queue Y1-064
Berkshire 34.5 kV
Feasibility/Impact Study Report

September 2012
#714693

Y1-064 Berkshire 34.5 kV Feasibility/Impact Study

General

RES Energy Storage Holdings LLC proposes to install PJM Project #Y1-064, a 4 MW Energy Storage generating facility. The point of interconnection is a distribution connection to the Berkshire – Sunbury 34.5 kV line. The generating facility has 4 MW (0 MW Capacity) in generating/discharging mode and 4MW of load in charging mode. The proposed location of the energy storage facility is in Berkshire Township, Delaware County, Ohio (See Figure 1).

RES Energy Storage Holdings, LLC requested that AEP evaluate two system configurations. Option 1 uses a 4.0 MW inverter capable of producing +/- 4.0 MW during charging/discharging operations, and option 2 uses a 4.5 MW inverter capable of producing +/- 4.5 MW during charging/discharging operations. Both options were evaluated by AEP's Distribution Department, though the project will only have a Maximum Facility Output (MFO) of 4.0 MW.

The proposed in-service date is December 31, 2013.

The objective of this Feasibility/Impact study is to determine budgetary cost estimates and approximate construction timelines for identified transmission facilities required to connect the proposed generating facilities to the AEP transmission system. These reinforcements include the Attachment Facilities, Local Upgrades, and Network Upgrades required to maintain the reliability of the AEP transmission system. Stability analysis is not required as part of this study.

Since there are two possible configuration schemes for the battery installation, the Feasibility/Impact Study report will be divided into the sections below in order to address impacts and estimated costs for each configuration.

- **I. Transmission Analysis**
- **II. Distribution Analysis**
  - **a. Option 1 - 4.0 MW configuration as noted**
  - **b. Option 2 - 4.5 MW configuration as noted**

I. Transmission Analysis

Attachment Facilities

It is understood that RES Energy Storage Holdings LLC will be responsible for all costs associated with connecting their 4MW energy storage generation to the Sunbury – Trent 34.5 kV line. Attachment costs are described in the AEP Distribution portion of this report.

Local and Network Impacts

The impact of the proposed generating facility on the AEP System was assessed for adherence with applicable reliability criteria. AEP planning criteria require that the transmission system meet single contingency performance criteria in accordance with the AEP FERC Form 715. Therefore, this criterion was used to assess the impact of the proposed facility on the AEP System. The RES Energy Storage Holdings LLC project was studied as a 4 MW (0MW Capacity) of generating facility in charging mode and 4MW of load facility in discharging mode; consistent with the interconnection application. Project #Y1-064 was evaluated for compliance with reliability criteria for summer peak conditions in 2015.

Potential network impacts were as follows for the point of interconnection:

Normal System (2015 Summer Conditions Charging mode)

- No problem identified

Single Contingency (2015 Summer Condition Charging mode)

- No problem identified

Multiple Contingency (2015 Summer Conditions Charging mode)

- No problem identified

Contribution to Previously Identified Overloads (2015 Summer Conditions Charging mode)

- No problem identified

Normal System (2015 Summer Conditions Generating mode Full Output)

- No problem identified

Single Contingency (2015 Summer Conditions Generating mode Full Output)

- No problem identified

Multiple Contingency (2015 Summer Conditions Generating mode Full Output)

- No problem identified

Contribution to Previously Identified Overloads (2015 Summer Conditions Generating mode Full Output)

- No problem identified

Voltage

PJM Queue Y1-064 Energy Storage project is modeled at Berkshire 34.5 kV Bus (Bus #246637). The voltage at the bus for normal system condition before the project is 1.061 PU. With project in-service, when the facility is in generating mode, the voltage at the bus is 1.062 PU, when the facility is in charging mode, the voltage is 1.059 PU. Therefore, the switching of the facility between generating and charging modes will result in 0.003PU steady state voltage fluctuation at Berkshire 34.5kV Bus.

Short Circuit Analysis

- No problems identified

Stability Analysis

- Not required

Additional Limitations of Concern

- None

Local/Network Upgrades

- None

Conclusion

Based upon the results of this Feasibility/Impact Study, the construction of the RES Energy Storage Holdings (PJM Project #Y1-064), a 4 MW Energy storage generating facility will require additional interconnection charges. AEP distribution will provide the interconnection cost in their study. The point of interconnection is a distribution connection to the Berkshire - Sunbury 34.5 kV Line. Local transmission upgrades are not required for this project.

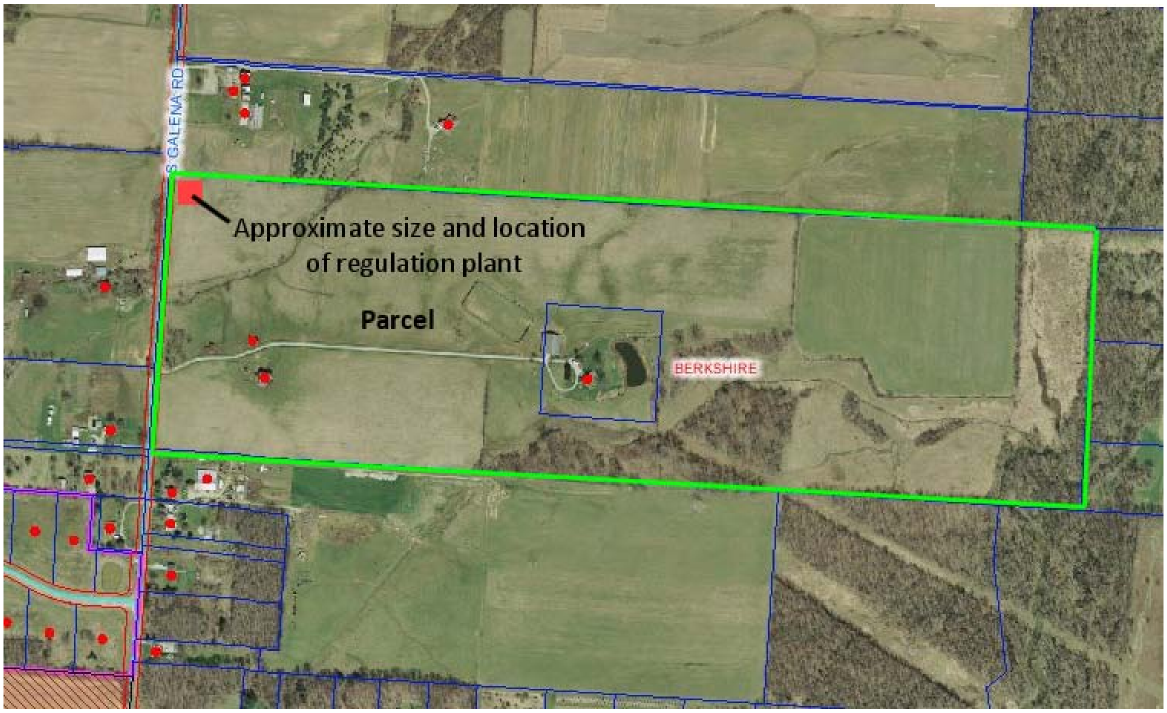

Figure 1: Proposed Y1–064 Project approximate Point of interconnection

II. Distribution Analysis

a. Option 1 – 4.0 MW

RES Energy Storage Holdings, LLC (Generator) has requested an interconnection impact study through PJM for a battery-powered distributed generation (DG) facility capable of 4.0MW maximum output power. The DG system consists of sixteen battery banks, connected as pairs. Each pair will feed a 500kW inverter, eight in total. The output of the inverters will connect via underground cables to four 1200kVA, 34.5kV – 0.20/0.20kV padmounted three winding transformers, and configured grounded-wye – delta/delta. The output of the transformers will connect with underground cables to a 5-way, 34.5kV padmount switchgear enclosure, which then will connect to AEP's pole-mounted primary metering via 0.1 miles of overhead wire. The primary metering pole will be the Point of Common Coupling (PCC) for the interconnection. AEP will install distribution facilities to interconnect the DG facility to its Berkshire Station, F-27032 34.5kV circuit.

b. Option 2 – 4.5 MW

RES Energy Storage Holdings, LLC (Generator) has requested an interconnection impact study through PJM for a battery-powered distributed generation (DG) facility capable of 4.5MW maximum output power. The DG system consists of four battery banks. The battery banks will feed a 4.5MW inverter. The output of the inverter will connect to a 4900 kVA, 34.5kV – 0.480kV padmounted transformer, and configured grounded-wye – delta. The primary side of the transformer will connect to a 34.5kV circuit breaker, which then will connect to AEP's pole-mounted primary metering via 0.1 miles of overhead wire. The primary metering pole will be the Point of Common Coupling (PCC) for the interconnection. AEP will install distribution facilities to interconnect the DG facility to its Berkshire Station, F-27032 34.5kV circuit.

Disclaimer

The contents of this feasibility/impact study apply only to the system that includes the aforementioned generation equipment as described in the Generation Interconnection application. All modeling is based on the PCC being located near AEP pole location #1885693-821501, on South Galena Rd (also known as County Road 34), west of Sunbury, Ohio, and interconnected as stated above.

Modeling and Assumptions

The Berkshire Station, F-27032 34.5kV circuit is a radial configuration, three-phase, multi-grounded, four-wire wye system. The primary voltage is 34.5kV line-to-line and 19.9kV line-to-ground. Nominal frequency is 60 Hertz. The F-27032 circuit is served from the 34.5kV station bus via a 138/34.5/13.8kV, 50/50/20 MVA transformer. There is one other distribution circuit fed from this bus, the F-27031 34.5kV circuit. The F-27032 circuit features three single phase voltage regulators. The 13.8kV tertiary winding of the station transformer is not currently in use.

The F-27032 circuit feeds south from Berkshire Station approximately 0.56 miles to the PCC location. The circuit's main line to the PCC consists of three-phase overhead line built with 3-556 kcmil aluminum bare primary wire and 1-#4/0 AWG 6201 aluminum alloy bare neutral wire.

Option 1 - 4.0 MW Generator Provided Information

This project will be participating in PJM's Frequency Regulation Market. The Generator has stated that the batteries require 4.0 MW during their charging periods. The inverter will operate at or very near unity power factor.

The Generator has stated that the maximum fault current contribution of the inverter, as a percentage of full load current, is 150%.

The BSG500KTL-U inverters manufactured by BYD Company Ltd. are IEEE1547 compliant and certified according to their published literature. They are designed to meet or exceed UL1741-2005 which includes testing for IEEE1547.1-2005.

Option 2 - 4.5 MW Generator Provided Information

This project will be participating in PJM's Frequency Regulation Market. The Generator has stated that the batteries require 4.5 MW during their charging periods. The inverter will operate at or very near unity power factor.

The Generator has stated that the maximum fault current contribution of the inverter, as a percentage of full load current, is 150%.

The supplied data sheet for the 4.5 MW Grid-Tied inverter manufactured by Dynapower Corporation states that the unit is designed and constructed to comply with UL1741 and IEEE1547-2003. AEP will require additional documentation (i.e. a Certificate of Compliance) from the manufacturer to show that the inverter conforms to UL1741 and IEEE1547 standards.

AEP Fault Values and Thevenin Impedances for both options

The following are bolted AEP symmetrical fault values and Thevenin impedances calculated at the PCC without the DG facility connected. Fault values and impedances are for a 34.5/19.9 kV system. System voltage can vary +/-5%.

- LLL = 3710 A LG = 4299 A
- Z1 = Z2 = 0.3460 + j 5.6265 ohms
- Z0 = 0.4846 + j 3.2945 ohms

<u>Analysis</u>

System Load Flows

The Generator has indicated that the batteries require 4.0 MW during their charging periods. Adding this load to the F-27032 circuit does not result in any abnormal or overload conditions to the AEP system.

With the DG at full output, and peak load conditions on the F-27032 Circuit, the DG will supply only a portion of the F-27032 Circuit load. With the DG at full output, and light load conditions on the F-27032 Circuit, the DG will carry the entire F-27032 Circuit load and supply power into the Berkshire Station 34.5 kV bus. Under this condition, if the other Berkshire Station circuit breaker opens during a contingency, the DG will supply enough power to cause a reverse power flow into the station transformer and the 138 kV transmission bus.

System Voltage Levels

To analyze the effect of a transition from full generator output to full battery charging load, circuit studies were run with the generator at full 4.0 MW output during both peak and light circuit loading conditions. Light loading was considered to be 25% of peak loading on the F-27032 circuit. The circuit voltage regulators were then locked to the calculated position and another study was run for both peak and light circuit loading conditions with the batteries charging, a 4.0 MW load. These studies reflect an instantaneous transition from full output to full charging load. Similar studies were conducted to simulate an instantaneous transition from full charging load to full output.

During peak loading conditions on the F-27032 circuit, the Generator will have negligible impact to the system voltage on the distribution circuit.

- When the generator transitions from full output to a full charging load, circuit modeling has indicated that voltage levels on AEP facilities will be within acceptable limits of 120 Volts +/- 5% (114 Volts to 126 Volts).
- When the generator transitions from full charging load to full output, circuit modeling has indicated that voltage levels on AEP will be within acceptable limits of 120 Volts +/- 5% (114 Volts to 126 Volts).

During light loading conditions, the Generator will have negligible impact to the system voltage on the distribution circuit.

- When the generator transitions from full output to a full charging load, circuit modeling has indicated that voltage levels on AEP facilities will be within acceptable limits of 120 Volts +/- 5% (114 Volts to 126 Volts).
- When the generator transitions from full charging load to full output, circuit modeling has indicated that voltage levels on AEP will be within acceptable limits of 120 Volts +/- 5% (114 Volts to 126 Volts).

Option 1 - 4.0 MW Circuit modeling indicates that the Generator's transition from full output to full charging load will cause a decrease in system voltage of 1.0 Volts (base 120 V), or 0.83%. Similarly, the Generator's transition from full charging load to full output causes an increase in system voltage of 0.83%. It is not likely that this decrease will be perceptible to other customers on the F-27032 Circuit. However, such transitions by the Generator (and consequent voltage fluctuations) shall not exceed more than 6 per hour.

Option 2 - 4.5 MW Circuit modeling indicates that the Generator's transition from full output to full charging load will cause a decrease in system voltage of 0.5 Volts (base 120 V), or 0.42%. Similarly, the Generator's transition from full charging load to full output causes an increase in system voltage of 0.42%. It is not likely that this decrease will be perceptible to other customers on the F-27032 Circuit. However, such transitions by the Generator (and consequent voltage fluctuations) shall not exceed more than 10 per hour.

System Fault Levels and Over current Protection

The addition of this DG equipment will subject AEP over current protection devices to increased fault current. These increases, measured at the PCC for both Option 1 and Option 2, are listed in Table 1.

With no DG equipment connected	**LLL (A)**	**LG (A)**
Option 1 - 4.0 MW	3710	4299
Option 2 - 4.5 MW	3810	4724
With DG equipment connected		
Option 1 - 4.0 MW	3710	4299
Option 2 - 4.5 MW	3821	4595

Table 1

The fault contribution increase caused by the DG will require a re-coordination of AEP protective circuit devices. Additionally, the Generator's final selection of a main protective device, now shown as either a motor operated air break switch or a circuit breaker, will need to be coordinated with the F-27032 Circuit breaker control settings.

The Generator's transformer (configured grounded-wye primary, ungrounded delta secondary) will provide a source for zero sequence current to the F-27032 circuit. This will decrease the sensitivity of the breaker's phase and ground relays that are utilized to detect line to ground faults on the circuit. The instantaneous and time delay pick up levels of the F-27032 phase and ground over current protective relays will need to be decreased to compensate for this desensitization while continuing to detect and isolate line to ground faults.

System Protection

The Generator responsibilities include providing adequate protection to AEP facilities due to events arising from the operation of the DG under all AEP distribution system operating conditions. The Generator is responsible for protecting their own facility under all AEP distribution system operating conditions whether the DG 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" provide the interconnection technical requirements for system protection for which the customer is responsible.

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 Ohio Customer Guide for Interconnection.

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.

The Generator is within the F-27032 breaker zone of protection. AEP reclosing interval times for the circuit breaker control are < 1 second to the first reclose and 5 seconds to the second reclose. The existing reclose times shall be modified to provide adequate time for the Generator to sense, initiate action, and disconnect from the circuit per the IEEE 1547 abnormal electric distribution system specification before any AEP distribution reclose action occurs.

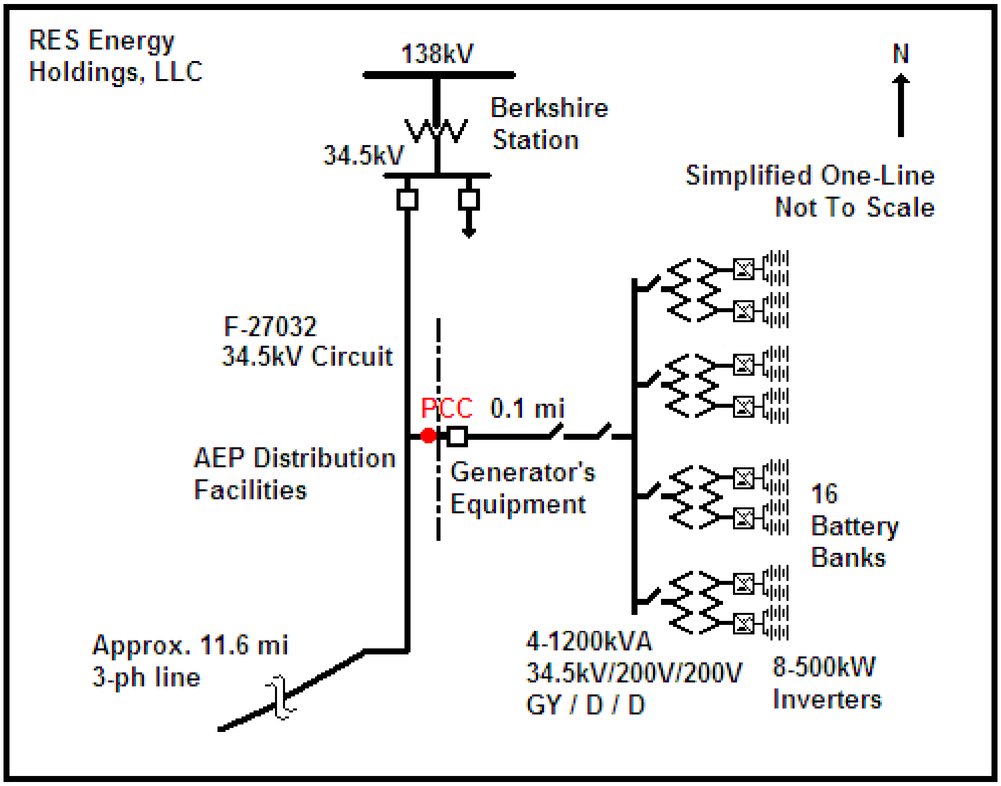

Figure 2. - Simplified One-Line Diagram (Option 1 – 4.0 MW)

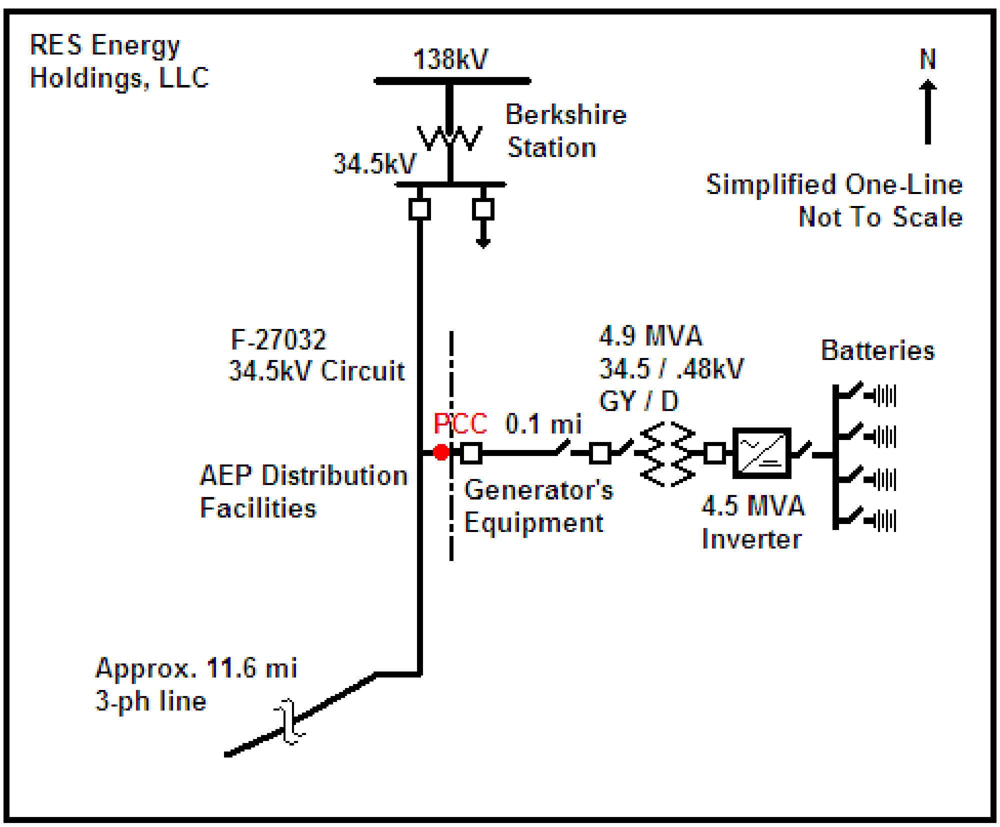

Figure 3. - Simplified One-Line Diagram (Option 2 – 4.5 MW)

Additional Generator Requirements for Interconnection

The Generator must meet all the requirements in the AEP GUIDE TO THE INTERCONNECTION OF DISTRIBUTED RESOURCES TO THE AEP DISTRIBUTION SYSTEM. Additionally, the Generator must meet the following requirements.

A. A final Distribution Impact Study may be required prior to confirming the interconnection agreement with the Generator.
B. Transformers
   - Option 1 – 4.0 MW It is requested that the Generator's 1200 kVA transformers be of a five-legged Core Form design or a Shell Form design. If practicable, AEP requests that the transformer be configured grounded-wye – grounded-wye/grounded-wye.
   - Option 2 – 4.5 MW It is requested that the Generator's 4.9 MVA transformer be of a five-legged Core Form design or a Shell Form design. If practicable, AEP requests that the transformer be configured grounded-wye – grounded-wye.
C. The Generator shall terminate its overhead line on the AEP primary metering structure utilizing dead-end insulators provided by AEP.
D. AEP requires that the Generator install a group-operated load break disconnecting device located on their first structure beyond the PCC. The disconnecting device must be accessible to AEP personnel, must be suitable for use by AEP personnel at all times and must be suitable for use by AEP as a protective tagging location. The disconnecting device shall have a visible open gap when in the open position and be capable of being locked in the open position. Each disconnecting device must have a ground grid designed in accordance with specifications to be provided by AEP. Operation must be restricted to AEP personnel and properly trained operators designated by the Generator. The disconnecting device must comply with the applicable current ANSI Standard from the C37 series of standards that specifies the requirements for circuit breakers, reclosers and interrupting switches.
E. The Customer is required to install an over current protective device beyond the aforementioned group-operated load break disconnecting device. This would meet the requirement in the Energy Distribution Guideline for Primary Metering Installations that the Customer install a protective device within one span of the terminating structure. This device will isolate faults from there to the Customer-owned 34.5kV equipment. The Customer shall contact AEP Ohio Project Design to coordinate the device or other 34.5kV protective equipment with AEP protective settings.
F. Ground Current Sources - The Generator must utilize protective relays to detect line-to-ground faults. The Generator shall provide adequate protection to comply with IEEE Standard 1547 to clear their generation source for all types of faults on the AEP system including any breaker failure event. Adequate protection requires that all fault types are cleared before equipment damage occurs to AEP facilities. If the Generator fails to provide adequate protection for faults on the AEP system, then the Generator will pay all costs associated with AEP facility damages.

G. Automatic Reclosing – Automatic high speed reclosing is applied to the transmission circuits supplying Trent Station. When any AEP source breakers trip and isolate the Generator's facilities, the Generator shall ensure that their generation equipment is disconnected from AEP facilities in accordance with requirements established in IEEE Standard 1547 item 4.2 and all item 4.2 sub-items prior to automatic reclosing by AEP. Automatic reclosing out-of-phase with the Generator's generation equipment may cause damage to the Generator's equipment. The Generator is solely responsible for the protection of their equipment from automatic reclosing by AEP.
H. All synchronization of the Generator with AEP must be done by the Generator.
I. The Generator must inform AEP if they desire remote access to real time primary metering information at the time they indicate their desire to proceed with this project.
J. The Generator has indicated that they will maintain output at unity power factor. The Generator must ensure that it does not export or import reactive power (vars) to the extent that it would drive voltage at the PCC outside of the 114-126 volt limit for all system loading conditions. The Generator may be asked by AEP to export or import reactive power to support system conditions.

Summary

AEP System Improvements for Interconnection

The proposed interconnection will require the following improvements to AEP facilities:

1. Replace pole 1885603-821511 and install a 3-phase buck pole with associated guying. Construct approximately 300' of overhead 34.5kV distribution line using 3-556 kcmil AL and 1-#4/0 AA conductors from the tap pole to a new AEP primary metering pole which will be the PCC. Relocate existing single phase fuse from pole 1885603-821511 to pole 1885693-821501.
2. Install a three-phase 34.5kV primary metering installation.
3. Install a communication system to tie the AEP primary metering into the AEP remote data monitoring system.
4. Reconfigure the F-27032 voltage regulator controls to allow for reverse power flow.
5. Re-coordinate the F-27032 Circuit over current protection scheme and automatic reclosing intervals to incorporate the Generator's 34.5kV main protective device.

Metering

The DG delivery into and out of the AEP system will be metered at 34.5kV. AEP will install a new 34.5kV primary metering installation (dual meter) at the PCC for ancillary load billing and operational monitoring.

Communication

An AEP communication system will be installed to remotely monitor load and other quantities in real time as metered at the PCC for operational and planning purposes.

Cost to the Generator

The conceptual estimate for the cost of AEP improvements previously described is $90,000.

Federal Gross-Up Tax, at the applicable rate, must be added to the total cost of the improvements.

It is estimated that the process for AEP to design and construct these improvements will take approximately six to nine months from the time an agreement is reached between AEP and the Generator to proceed.