

***Generation Interconnection
Combined Feasibility / System
Impact / Facility Study Report***

for

***PJM Generation Interconnection Request
Queue Position Z2-027***

***Pasquotank 34.5kV
14MW Capacity / 20MW Energy***

September / 2014

Introduction

This Combined Feasibility & System Impact Study has been prepared in accordance with the PJM Open Access Transmission Tariff, 36.2 & 205, as well as the Feasibility Study Agreement between Interconnection Customer (IC), and PJM Interconnection, LLC (PJM), Transmission Provider (TP). The Interconnected Transmission Owner (ITO) is Virginia Electric and Power Company (VEPCO).

Preface

The intent of the Combined 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, if any, is included in the System Impact Study.

The 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 associated with them will be addressed when seeking an Interconnection Agreement as outlined below. Developer will also be responsible for providing and installing metering equipment in compliance with applicable PJM and Transmission Owner standards.

General

Elizabeth City Solar, LLC, the Interconnection Customer (IC), has proposed a solar generating facility located at US 17 Bypass at Old Foreman Bundy Road in Elizabeth City, NC. The installed facilities will have a total capability of 20 MW with 7.6 MW of this output being recognized by PJM as capacity. The proposed in-service date for this project is 10/31/2014.

This study does not imply an ITO commitment to this in-service date.

Point of Interconnection

Z2-027 will interconnect with the ITO distribution system via a tap onto the existing 34.5kV circuit 434 which is fed out of Pasquotank 230 / 34.5kV substation.

Cost Summary

The Z2-027 project will be responsible for the following costs:

Description	Total Cost
Attachment Facilities	\$186,677
Direct Connection Network Upgrades	\$
Non Direct Connection Network Upgrades	\$
Non Direct Connection Local Upgrades	\$386,858
Contribution for Previously Identified Upgrades	\$
Total Costs	\$573,535

Attachment Facilities

The ITO has an existing 34.5 kV distribution line in proximity to the IC's site served from a 230/34.5 kV transformer in Pasquotank substation. To provide the interconnection the ITO will:

- Install 4 new poles
- Install 400 feet of 477 Al. line to a new poles
- All metering needed for interconnection of generation and auxiliary load
- G&W Viper ST w/SEL 651R-2 Control Recloser
- Install SEL 735 Power Quality Monitoring Relay and associated control wiring
- Install two single phase pole mounted transformers to supply power to the Recloser controls and to the Power Quality monitoring relay
- One Disconnect Switch to serve as an isolation point
- Transfer trip equipment at the IC's site

The estimated cost of the installation of the new attachment facilities to provide the interconnection is \$186,677.00. In addition to the upfront cost of the Attachment Facilities there will be an ongoing monthly charge for the Operation and Maintenance of the Attachment Facilities. That Monthly charge is 0.543% of the installed cost of the Attachment Facilities. These costs do not include CIAC Tax Gross-up. The single line is shown in Attachment 1.

Non-Direct Connection Cost Estimate

ITO will provide an interconnection point to support a 20 MW generation interconnection on circuit 434 out of Pasquotank Substation. Circuit protection relay equipment will be upgraded. Transmission islanding transfer trip equipment will be added to the 2020 line at Pasquotank, Winfall and Elizabeth City substations. Distribution transfer trip equipment will be installed at Pasquotank substation with a corresponding transfer trip receiving unit at the customer facility.

Distribution Circuit Reconductoring

- Reconductor 3,400' of existing 2/0 Cu. to 477 Al. Primary and 246.9 Al. Neutral

Pasquotank Substation

- One (1), 230kV relay accuracy CCVT's
- One (1), Single Phase CCVT Potential Box
- Conductor, connectors, conduit, control cable, foundations and grounding material as per engineering standards
- One (1), Co-Gen Transceiver Rack
- One (1), SEL-2505/6 Module on Transfer Trip rack

Winfall Substation

- One (1), Transfer Trip Transmitter

Elizabeth City Substation

- One (1), Transfer Trip Transmitter

Total cost for all distribution upgrades equals \$386,858.00. The total preliminary cost estimate for Non-Direct Connection work is given in the table below:

Description	Total Cost
Pasquotank Substation (n4059)	\$
Reconductor line 434 (n4060)	\$
Windfall Substation (n4061)	\$
Elizabeth City Substation (n4062)	\$
	\$386,858

The estimated time for engineering, material acquisition and construction of this interconnection is approximately 6 months.

Interconnection Customer Requirements

VEPCO Facility Connection Requirements as posted on PJM's website
<http://www.pjm.com/~media/planning/plan-standards/private-dominion/facility-connection-requirements1.ashx>

IC required to provide:

- Installation of all conductors between the generating facility and POI
- Installation of pad mounted transformers
- Installation of a three phase interruption device
- Installation of all generator breakers and associated equipment
- Communication lines for all metering
- Communication between customer breaker and Utility Pasquotank Substation

In addition to the Attachment Facilities indicated above, to provide a transfer trip circuit protection scheme, the IC will also be responsible for providing and maintaining telephone lines to the ITO's metering equipment at the Point of Interconnection and between the Company's

recloser, Pasquotank substation and Customer’s facility. The IC provided 34.5 kV 3-phase circuit will interconnect underground at the Point of Interconnection which will be the load side terminals of the ITO provided pole mounted bi-directional meter. It will be the IC’s responsibility to obtain any required right-of-way between the ITO’s existing facilities and the Point of Interconnection.

ITO Technical Requirements

The ITO has completed a review of PJM Queue Z2-027 which is an inverter (UL1741/IEEE 1547 certified) based interconnection consisting of a total of fourteen (14) inverters. The POWER-ONE ULTRA 1500-TL-OUTD-2-US-690 inverters are rated at 1500 kW and 690 Vac. The inverter system is installed in blocks of single 1500 kW inverters connected to a three (3) phase 1500 kVA pad mounted transformer. All transformers are listed as 19.9/34.5 kV – 690 V with a wye-ground (primary) – wye (secondary) winding configuration. The resulting protection requirements are based on the following information:

- The IC's generation facility will be paralleled with the ITO system by connection to the Pasquotank Distribution Circuit 434 via a new installed Automatic Line Recloser (ALR) 434RXXX. Circuit 434 is sourced by Pasquotank Transformer # 1 and Line 2020 (Winfall – Elizabeth City).
- Pasquotank Circuit 434 feeder breaker has reclosing times at 10 seconds and 45 seconds after the first trip.
- Transmission Line 2020 has both time delayed and Instantaneous reclosing applied on its Terminal Breakers.
- The load data for the pertinent sectionalizing devices are as follows:
 - Pasquotank Circuit 434 (43432) has typical "light" loading of 1.76 MVA
 - Pasquotank Transformer #1 & Bus #1 has typical "light" loading of 2.59 MVA
 - Line 2020 has typical "light" loading of 27.98 MVA
- IC generation facility will not be permitted during periods when the source circuit is switched into an abnormal configuration.

Based on the projected minimum loads given for applicable utility sectionalizing devices, the following minimum "Local Load to IC Generation Capacity" ratios will apply for this installation:

<i>Utility Device</i>	<i>Minimum Ratio</i>
CB 43432	0.06
Transformer #1	0.09
Line 2020	0.95

Based on the size and type of this generation, the applicable ITO Standards and the minimum ratios applicable for this installation, the following requirements will need to be met before parallel operations can be granted:

1. Installation of a ITO owned Automatic Line Recloser (ALR) at the point of interconnection (POI) with all required relaying (described in table 3 below) at the IC expense
2. Installation of Direct Pilot Wire Tripping (or Transfer Trip) function from the utility devices (CB 43432, Distribution Bus, Substation Transformer #1 and Line #2020 [i.e. 247T2020 and 2020T2021]) to the new ALR 434RXXX at the IC expense. Such direct tripping functions should sectionalize the IC generation for any opening of the respective device. The direct trip control feature is meant to ensure that a prolonged or permanent islanding condition (with the IC generation supplying utility load in the absence of the utility source) will not be set-up.
3. Installation of an additional ITO owned Protective Relaying (SEL-735 Power Quality package) at the POI (ITO Metering Instrument Transformer Cabinet) with all required metering/relay functionality at the IC expense. **The power source (single phase, 120 Vac) to this Power Monitor shall be supplied from a 2 kVA or larger Station Service (19,920 – 120 Vac) source (low exposure) independent of any other generation, load or exposure.** Such Protective Relaying should aid in the determination of on-going harmonic levels among other information regarding the interconnection site as well as providing a trip initiation to the ALR when either harmonic standard limits are exceeded or other undesirable conditions are detected.

The voltage and frequency “Default Max” clearing times, listed in Table 1, are derived from IEEE-1547a-2014 (Amendment to IEEE Standard 1547-2003). The overall anti-islanding “Default Max” clearing time, listed in Table 1, is derived from IEEE Standard 1547-2003 (R2008). The IC will be required to apply all the enabled protection settings and not exceed the Default Max clearing times (Table 1) on “all inverters”. If the IC chooses to adhere to IEEE 1547 default maximum clearing times and not the ITO standards, the IC shall provide detailed, manufacturer-supplied computer simulation models (Aspen OneLiner, Matlab, PSSE, and PSCAD) of the PV plant, to include full control and hardware details, needed to investigate IC impacts. In addition if the IC adheres to the ITO clearing times, test results from a nationally recognized laboratory need to be provided for review.

Currently, this site is not intended to operate for grid support functionality. Therefore, the following inverter functions, in Table 1, are to be disabled: LVRT, HVRT, LFRT, ZVRT, VAR Support, and Voltage Regulation.

Function		Set Point	Clearing Time (sec)	
			Default Max	DNCP
27	Under-voltage	$V < 45\%$ nominal voltage	0.16	0.083
		$45\% \leq V < 60\%$	1.00	0.083
		$60\% \leq V < 88\%$	2.00	0.083
59	Over-voltage	$110\% < V < 120\%$	1.00	0.083

		$V \geq 120\%$ nominal voltage	0.16	0.083
81U	Under-frequency	$F < 57.0$ Hz	0.16	0.083
		$F < 59.5$ Hz	2.00	0.083
81O	Over-frequency	$F > 60.5$ Hz	2.00	0.083
		$F > 62.0$ Hz	0.16	0.083
	Overall Anti-Islanding	Disconnect inverter from system PCC	2.00	0.083
	Steady State Power Factor (± 0.95 Control Range)	DISABLE		
LVRT	Low Voltage Ride Through	DISABLE		
HVRT	High Voltage Ride Through	DISABLE		
LFRT	Low Frequency Ride Through	DISABLE		
ZVRT	Impedance Voltage Ride Through	DISABLE		
	VAR Support	DISABLE		
	Voltage Regulation	DISABLE		

Table 1: DG Inverter Settings

All the data, requested in Table 2, is necessary to perform short-circuit studies. If the inverter manufacturer provides Aspen OneLiner parameters, a detailed test report must be provided to ITO for review. The test report should include test environment and method, sequence impedance calculations, and any assumptions used.

Inverter Data (Valid for Widest Range of Faults up to 6 Cycles)	P.U. Value
Inverter Equivalent MVA Base	
Short-Circuit Equivalent Positive Sequence Resistance (R1)	
Short-Circuit Equivalent Positive Sequence Reactance (XL1)	
Short-Circuit Equivalent Negative Sequence Resistance (R2)	
Short-Circuit Equivalent Negative Sequence Reactance (XL2)	

Short-Circuit Equivalent Zero Sequence Resistance (R0)	
Short-Circuit Equivalent Zero Sequence Reactance (XL0)	

Table 2: IC Inverter Data provided in per-unit of inverter MVA base.

The required relay functions and the corresponding set points, with each sectionalizing all of the IC’s generation and always enabled on the ALR regardless of the operating condition, are listed in the following table:

Function		Set Point	Duration to Disconnection (sec)
27	Undervoltage	75 % of nominal operating voltage	2.0
59	Overvoltage	110% of nominal operating voltage	2.0
81U	Underfrequency	59.5 Hz	2.0
81O	Overfrequency	60.5 Hz	2.0
51	Phase Time-delay Overcurrent	Set for minimum, with adequate load allowance	Maintain proper coordination with DG owner high side fuse

Table 3: ALR Set Points

Moreover, harmonics (voltage and current) if not controlled can be a source of problems on the ITO network. Though it is definitive that small scale PV systems (i.e. about 10 kW dc or less) have little to no significant harmonic effects on the system provided their associated converter meets the IEEE standard 519 (Guideline for Harmonic Control and Reactive Compensation of Static Power Converter), the impacts of larger scale PV systems are far less certain. It is a general consensus that a concentration of small sources of harmonic distortion - as little as they could be - can have a significant effect on the overall ITO network's power quality as the effect of harmonics are cumulative. It is imperative that harmonics are not ignored.

In Summary, **Power Quality baseline readings** will be required at the POI before and after the interconnection is completed in order to monitor the harmonic effects of the Generation unit and will be obtained at the IC’s expense. Also, if there is evidence that the Total Harmonic Distortion (THD) or Total Demand Distortion (TDD) is greater than or equal to 5%, or harmonic distortion for any single harmonic is greater than or equal to 3%, the IC would be required to add a filtering system to its installation to meet the requirements of IEEE 519.

Furthermore, as ITO gains more knowledge about the inverter technology and the effect of inverter based distributed generation on ITO Electric Power System (EPS), ITO may call for additional review of existing and/or pending interconnection requests. ITO has learned through recent IEEE/PES/PSRC work, WG C-17 Report as well as through participation in the IEEE 1547 Standard working groups, that Photovoltaic (PV) or Solar (inverter-based) generation

marketed to North America utilize back-to-back converters/inverters similar to a Type 4 Wind Turbine Generator (WTG). One characteristic, that is of particular concern, is the inverter's design choice to not produce any zero sequence current I_0 . Since $I_0 = V_0 / Z_0$, the Z_0 (further represented by $R_0 + jX_0$) in effect becomes very (or infinitely) large. Even though a wye-ground – wye-ground transformer connection passes zero sequence current, there will be no zero sequence current to pass to the fault location with inverter based generation. **Essentially, effective grounding cannot be maintained with such a transformer winding configuration and ITO's effectively grounded EPS must remain effectively grounded.** With that established, for a condition where the utility opens all three phases to a system segment of its EPS to clear a phase-to-ground fault and the IC connected to the islanded segment of the EPS for a period of time, phase-neutral voltages on the un-faulted phases will rise to near phase-to-phase values.

To come back to the result of current review, initial analysis has shown that during a system disturbance with a loss of the grounded utility source, the voltage on un-faulted phases of the circuit will rise to full phase-to-phase voltage which could damage ITO's equipment (rated for a phase-to-neutral voltage), other ITO customer's equipment, and also IC's equipment.

ITO current requirement for a solution to that concern is for the IC to install **two-winding transformers with a grounded-wye (towards utility) and a delta on the other side** (isolation transformer). An alternative option would be to apply a **ground bank transformer [zig-zag or wye (utility side) – delta (floated)]** at (near) the point where the generation is connected. The objective is to obtain a balance of the ground fault current such that effective grounding is maintained on the utility ($R_0/X_1 \leq 1$ and $X_0/X_1 \leq 3$) without adversely impacting ground fault protection and coordination. This design will pass enough zero sequence current to keep the circuitry effectively grounded in all cases; but not introduce so much zero sequence current that coordination (pick-up, time, and reach) cannot be successfully achieved. It should be noted by the IC's Engineering/Technical representative that if a ground bank installation is utilized, the Protection and Control scheme design must remove/prevent the connection of all/any inverters with the ITO EPS at ALL times when the ground bank is off-line (not in service), for any reason.

With this reference perspective established, it will be the IC's Engineering/Technical representative's responsibility to select and apply the proper size ground bank or isolation transformer with H0 bushing-to-ground impedance (resistance). While ITO may recommend a range with respect to the neutral ground resistance (NGR) size or base impedance of the grounding bank, ITO will not size the equipment for the IC. ITO will only review and grant approval of the design from ITO perspective. Additionally, it is important that details on the grounding transformer or Grounded-Wye/Delta isolation transformers be provided as soon as possible for ITO to review due to the importance of the effective grounding and coordination issue that may be introduced.

Since the installation of the ITO-owned ALR at the POI, associated relaying, as well as the SEL-735 Power Quality package and the related additional substation work are all provided at the IC expense, ITO will need to work out the details to coordinate the planned interconnection with the associated engineering, equipment acquisition and installation times. Please note that the IC will not be allowed to interconnect until all the permanent facilities and associated relaying are installed, tested and fully functional.

Finally, please send ITO details concerning the IC's final inverter model, interface transformer specifications (i.e. transformer impedance, load losses, etc.), the applied inverter trip points as well as the high side fuse make, model and rating information of the isolation transformer as soon as possible. If the IC chooses to utilize a grounding transformer to comply with ITO effective grounding requirements, please provide ITO with the grounding bank information (type, load losses, zero sequence impedance, maximum neutral fault current, etc.) for review and approval. Please contact the ITO at (804) 257-4057 if you have any questions or need additional information.

Revenue Metering and SCADA Requirements

PJM Requirements

The Interconnection Customer will be required to install equipment necessary to provide Revenue Metering (KWH, KVARH) and real time data (KW, KVAR) for IC's generating Resource. See PJM Manuals M-01 and M-14D, and PJM Tariff Sections 24.1 and 24.2 via communication links installed, owned, and maintained by the IC.

Network Impacts

The Queue Project Z2-027 was studied as a 20.0 MW (Capacity 14.0 MW) injection at the Tanglewood 230 kV substation in the Dominion area. Project Z2-027 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners) for summer peak conditions in 2018. Project Z2-027 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Contingency Descriptions

The following contingencies resulted in overloads:

None

Generator Deliverability

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

None

Multiple Facility Contingency

(Double Circuit Tower Line contingencies were studied for the full energy output. The contingencies of Line with Failed Breaker and Bus Fault will be performed for the Impact Study.)

None

Short Circuit

(Summary of impacted circuit breakers)

New circuit breakers found to be over-duty: None

ITO will require a generator step up transformer configuration of wye grounded (primary)/delta (secondary) with provisions for external resistance grounding of the primary with the level of resistance to be determined by the IC and approved by the ITO. If a wye (primary)/wye (secondary) transformer configuration is utilized the IC will apply a ground bank configured transformer [zig-zag or wye (interconnection side) – delta (floated)] at (near) the point where the generation is connected. In addition prior to interconnection the IC will need to provide to the ITO specific inverter information including the model and parameter data required for a short-circuit analysis including Positive, Negative and Zero Sequence Resistance and Reactance for the initial 4 to 6 cycles.

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

(Summary of the VAR requirements based upon the results of the steady-state voltage studies)

To be determined

Stability and Reactive Power Requirement for Low Voltage Ride Through

(Summary of the VAR requirements based upon the results of the dynamic studies)

Not required as PJM Studies only performed for small resources where existing stability margins are limited.

Light Load Analysis

(Study to determine that the Transmission System is capable of delivering the system generating capacity at light load)

Light Load Studies not required for solar generation.

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)

None

Potential Congestion due to Local Energy Deliverability

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.

Note: Only the most severely overloaded conditions are listed below. 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 shall study all overload conditions associated with the overloaded element(s) identified.

None

ITO Analysis

ITO assessed the impact of the proposed Queue Project #Z2-027 interconnection of 20.0 MW of energy (Capacity 14 MW) for compliance with reliability criteria on ITO's Transmission

System. The system was assessed using the summer 2018 RTEP case provided to ITO by PJM. When performing a generation analysis, ITO's main analysis will be load flow study results under single contingency and multiple facility contingency (both normal and stressed system conditions). ITO's criteria considers a transmission facility overloaded if it exceeds 94% of its emergency rating under normal and stressed system conditions. A full listing of ITO's Planning Criteria and interconnection requirements can be found in the ITO's Facility Connection Requirements which are publicly available at: <http://www.dom.com>.

The results of these studies evaluate the system under a limited set of operating conditions and do not guarantee the full delivery of the capacity and associated energy of this proposed generation facility under all operating conditions. NERC Planning and Operating Reliability Criteria allow for the re-dispatch of generating units to resolve projected and actual deficiencies in real time and planning studies. Specifically NERC Category C Contingency Conditions (Bus Fault, Tower Line, N-1-1, and Stuck Breaker scenarios) allow for re-dispatch of generating units to resolve potential reliability deficiencies. For ITO's Planning Criteria the re-dispatch of generating units for these contingency conditions is allowed as long as the projected loading does not exceed 100% of a facility Load Dump Rating.

As part of its generation impact analysis ITO routinely evaluates the impact that a proposed new generation resource will have under maximum generation conditions, stress system conditions and import/export system conditions. The results of these studies are discussed in more detail below.

Category B Analysis (Single Contingency):

1. System Normal – No deficiencies identified
2. Critical System Condition (No Surry 230 kV Unit) – No deficiencies identified.

Category C Analysis: (Multiple Facility Contingency)

1. Bus Fault - No deficiencies identified
2. Line Stuck Breaker - No deficiencies identified
3. Tower Line – No deficiencies identified

Attachment 1.

System Configuration

