Generation Interconnection
System Impact Study Report

For

PJM Generation Interconnection Request
Queue Position AB2-188

Creswell 34.5kV
13.8 MW Capacity / 20 MW Energy

December / 2018

Introduction

This System Impact Study (SIS) has been prepared in accordance with the PJM Open Access Transmission Tariff, Section 205, as well as the System Impact Study Agreement between Creswell Hwy 64 Solar, LLC, the 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 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 IC. As a requirement for interconnection, the IC 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 IC 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 System Impact Study is performed.

The 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 IC 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

The IC has proposed a solar generating facility located in Washington County, NC. The installed facilities will have a total capability of 20 MW with 13.8 MW of this output being recognized by PJM as capacity. The proposed in-service date for this project is 12/01/2021. **This study does not imply an ITO commitment to this in-service date.**

Point of Interconnection

AB2-188 will interconnect with the ITO distribution system at a new 34.5kV circuit connecting through a new 115/34.5kV substation tapping on Creswell – Riders Creek 115kV line.

Cost Summary

The AB2-188 interconnection request will be responsible for the following costs:

Description	Total Cost
Attachment Facilities	$ 227,973
Direct Connection Network Upgrades	$ 65,200
Non-Direct Connection Network Upgrades	$7,176,673

Total Costs	**$7,469,846**

Transmission Owner Scope of Work

The requested site will be connected to a new 34.5 kV Circuit out of new 115/34.5kV substation tapping on Creswell – Riders Creek 115kV line.

Attachment Facilities

The new Attachment Facilities are:

- Install 5 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 Engineering, Material, and Construction for installation of the new attachment facilities to provide the interconnection is $227,973. These costs do not include CIAC Tax Gross-up. The single line is shown below in Attachment 1.

The IC will also be responsible for an ongoing monthly operation and maintenance cost of 0.543 percent of the estimated cost of the new facilities of $227,973. The calculation will be $227,973 x 0.00543 = $1,237.89

Local Non-Direct Connection Cost Estimate

Complete the following activity regarding PJM Network Upgrade **n5975**, build a new AB2-188 115/34.5 kV Substation. The work includes the following:

- Procuring land, Grading, grounding, site preparation and permitting necessary for the new sub
- Two (2), 115kV, 2000A vertical break line switch w/ vacuum attachments
- One (1), 115kV, 2000A center–break switch
- One (1), Motor operator for 115kV switch
- One (1), 115kV, circuit switcher (verify ratings with calculation prior to selecting vendor)
- One (1), 115kV, Relay accuracy CCVT
- One (1), 800A Wave Trap
- One (1), Line tuning trap
- One (1), 115-36.5kV, 33.6MVA, LTC, DY Transformer
- Three (3), 90kV MO, 74kV MCOV Station Class Lightning Arresters
- Three (3), 30kV MO, 24.4kV MCOV Station Class Lightning Arresters
- One (1), 34.5kV, 3000A, 40kA, SF6 Circuit Breaker without relays
- One (1), 34.5kV, 1200A,end-break switch
- Six (6), 34.5kV, 1200A Hook stick Disconnects
- Six (6), 34.5kV, 2000A Vertical Mounted Hook stick Disconnects

- One (1), 34.5kV, 1200A, Alduti-Rupter Load Break Switch
- Three (3), 27kV MO (DI), 22kV MCOV lightning Arresters
- One (1), UG circuit getaway structure (Verify with Dist. Engineering)
- Two (2), 19.9kV, 167kVA station service transformers
- Three (3),34.5kV, oil filled PT (300/175:1)
- One (1), 4800KVAR @ 37.4kV capacitor bank
- One (1), 34.5kV, 600A, SF6 cap-switcher
- Three (3), 600V, 2000/5 blinding CTs
- Six (6), 30kV, MO, 24.4kV MCOV lightning Arresters
- Eleven (11), 34.5kV, SMD-20 fuse mount and Five (5), 23-kV, 12A current limiting fuse (verify ratings with calculations)
- One (1), 24'X30' Expandable Control Enclosure
- One (1), 135Vdc, 500Ah battery (verify ratings with calculation)
- One (1), 135Vdc, 50A battery charger (verify ratings with calculation)
- One (1), High Voltage Protection (If needed by Telco)
- Steel structures and 3 ¼" x 3 ¼" x ¼" Aluminum angle as required to create 34.5kV bus.
- One (1), 75' Static Pole (By Transmission)
- Fence as required
- Install any necessary aluminum bus, conductor, steel pipe stands, foundations, conduit, control cable, cable trough and grounding as per Dominion Substation Engineering Standards
- Install oil containment for one (1) transformer
- One (1), Single Phase CCVT Potential M.U. Box
- One (1), SEL 387 Distribution TX Diff w/o L-Breaker Panel
- One (1), SPR Relay/Auxiliary Package
- One (1), SEL 2411 TX Equipment Annunciator
- One (1), SEL 311C Distribution Bus Panel
- One (1), Three Phase Potential M.U. Box
- One (1), Single SEL 451-5 Circuit Panel
- One (1), Capcon Control (Cap SW) Box
- One (1), Cap bank C.T. M.U. Box
- One (1), Station Service Potential M.U. Box
- One (1), 800A SS AC Distribution Panel
- One (1), 225A Outdoor Distribution AC NQOD
- One (1), 225A 3 PH Throw over Switch
- One (1), 600A Safety Switch
- One (1), Station Ambient Temperature Monitor
- One (1), Wall Mounted Battery Monitor
- One (1), SEL 3530 (RTAC) Comm Panel
- One (1), SAM-900 Station Annunciator
- One (1), SEL 2411 RTU
- One (1), Station Fiber Management Panel
- One (1), Transformer Fiber MU Box
- One (1), Network Rack

- One (1), Security Rack
- One (1), SEL – 451-5 DG Support Panel (w/ TTT & Telco DG TT)
- One (1), Telephone interface Box
- One (1), DG Receiver Cabinet – AC (No upline recloser)
- One (1), 800A Wave trap at Riders Creek Tap
- Two (2) 115kV backbones
- Two (2) 3-pole guyed DOM DDE structures
- New conductor from 3-pole to backbones
- New shield wire (four) from 3-pole to backbones
- Two (2), Floating Dead ends
- Two (2), 3-poles without statics
- Two (2), 3-poles with statics
- Two (2), 3-phase temporary risers
- Temporary conductor/shield wire

Total estimated cost of the Engineering, Material, and Construction for all substation upgrades equals $7,176,673. The estimated time for engineering, material acquisition and construction of this interconnection is 36 months.

Local Direct Connection Cost Estimate

Complete the following activity regarding PJM Network Upgrade **n5976**. Install new 34.5kV circuit including getaway from a new AB2-188 115/34.5 kV substation to IC site. Transfer existing 34.5kV circuit from the IC site to a new circuit from AB2-188 substation.

Total estimated cost of the Engineering, Material, and Construction for all distribution upgrades equals $65,200. The estimated time for engineering, material acquisition and construction of this interconnection is 36 months.

Transmission Owner Technical Requirements

This is an inverter (IEEE 1547/UL1741 Certified) based interconnection which consists of ten (10) SMA SC2200-US inverter units, each with a rated maximum output of 2.2MVA at 385Vac. Based on IC drawing, revision date 21APR2016, the inverter system is in single blocks of 2.2MVA connected to a three (3) phase 2.0MVA step-up transformer. All transformers are listed as 34.5/19.9 kV (Wye-grounded) - 385V (Wye). Creswell Hwy Solar, LLC has the capacity to produce 22.0MW ac (Unity Power Factor) at a nominal operating voltage of 385V ac. Creswell Hwy Solar, LLC shall be clipped at 20.0MW ac (Unity Power Factor) at a nominal operating voltage of 385V ac. The resulting protection requirements are based on the following information:

- No more than 20.0MWac of total generation will be in parallel with the ITO system at any one time.
- The IC's generation facility will be paralleled with the ITO system by the following connections:
  - The IC's generation facility will be connected to a new 34.5 kV distribution circuit XXX, via a new Automatic Line Recloser (ALR) XXXRXXX which is sourced by a new

34.5kV circuit breaker, new 34.5 kV Bus #1, new 33.6MVA 115/34.5kV transformer, and existing 115kV Line 101.

- 115kV Line 101 currently has existing, or existing project queue IC totaling 44.0MWac.
- The new 33.6MVA 115/34.5kV transformer currently has existing project queue IC totaling 20.0MW ac (PJM# AB2-188).
- The new 34.5kV distribution circuit XXX currently has existing project queue IC totaling 20.0MW ac (PJM# AB2-188).
- The new 34.5kV circuit breaker will have reclosing times at 10 seconds and 45 seconds after the first trip.
- IC parallel operation will not be permitted during periods when the source circuit is switched into an abnormal configuration.
- The load data for the pertinent sectionalizing devices are as follows:
  - New 34.5kV circuit breaker has a typical "light" loading of 0.0 MVA.
  - New 33.6MVA 115/34.5kV transformer has a typical "light" loading of 0.0 MVA.
  - Existing 115KV Line 101 has a typical “light” loading of -5.5MVA.

Based on projected minimum loads given for the applicable ITO sectionalizing devices, the following minimum "Light Load to cumulative Generation Capacity" ratios will apply for this installation. Transfer trip is required from each zone with a ratio less than 3:1.

ITO Device	*Minimum Ratio*
New 34.5kV Circuit Breaker	0.00
New 33.6MVA 115/34.5kV Transformer	0.00
115kV Line 101	-0.125

Table 2. Light Load to Generation Ratio

Based on the size and type of this generation, the applicable ITO Standards and the minimum load ratios applicable for this installation, the following requirements must be met in their entirety before permission to parallel operations can be granted:

1. Installation of an ITO owned Automatic Line Recloser (ALR) at the point of common coupling (POI) with all required relaying (Table 3: ALR Set Points).
2. 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. **The power source (single phase, 120 V ac) to this Power Monitor shall be supplied from a 2kVA or larger Station Service (19.919kV – 120 V ac) 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.
3. 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. The PV plant shall meet the IEEE Standard 519 – 2014 “IEEE Recommended Practice and Requirements for Harmonic Control in Electric

Power Systems". If there is evidence that the Voltage Total Harmonic Distortion (THD) is greater than or equal to 5%, Current Total Demand Distortion (TDD) is greater than or equal to 5%, or any single harmonic exceeds the distortion limits specified in IEEE Standard 519-2014, the IC would be required to add a filtering system to its installation to meet the requirements of IEEE 519 – 2014.

4. Effective Grounding: Due to the step-up transformer configuration being Wye-grounded / Wye, the ITO electric power system will not be effectively grounded when an upline device opens to clear a phase-ground fault and the DG remains connected to the islanded segment for a period of time. The temporary overvoltage will be mitigated by the following:

    a. Install Direct Pilot Wire Tripping (Transfer Trip) from each of the up-line ITO devices to the DG site recloser.
    b. A light load to generation ratio greater than 3:1 for the nearest upline device from the POI.

5. Substation upgrades listed below are required:

    a. Add transmission line transfer trip to Line 101 to serve as an input to the SEL-451 DG panel relay to send transfer trip to the POI recloser to clear all sources to a transmission fault. Ensure that line terminal station has been upgraded to provide line transfer trip functionality.

    b. Add the DG relay panel; SEL-451 and SEL-735.

    c. Install Direct Pilot Wire Tripping (or Transfer Trip) from each of the up-line ITO devices: new 34.5kV circuit breaker, new 34.5kV Bus#1, and new 33.6MVA 115/34.5kV transformer to the DG site recloser. Transfer trip is required due to the lack of light load to maintain an effectively grounded system when the up-line sectionalizing device operates for a line to ground fault.

    d. Wire new 33.6MVA 115/34.5kV transformer LORs 86T1 and 86T1BU and Bus#1 LOR 86B1 to trip and prevent reclosing of new 34.5kV circuit breaker.

    e. Add Potential Transformers (PT's) to 34.5kV Bus#1 to provide potential to DG panel relaying.

    f. Add standard microprocessor protection relay panel for new 34.5kV circuit breaker.

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	Under voltage	75 % of nominal operating voltage	2.0
59	Overvoltage	110% of nominal operating voltage	2.0

81U	Under frequency	59.5 Hz	2.0
81O	Over frequency	60.5 Hz	2.0
51P	Phase Time-Overcurrent	Set for minimum, with adequate load allowance	Maintain proper coordination with IC high side fuse
51G	Ground Time-Overcurrent	Set above DG site transformers cumulative inrush current (3^{rd} Harmonic)	Maintain proper coordination with DG site transformers cumulative inrush current and upstream ground protection

Table 3: ALR Set Points

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.

Interconnection Customer Requirements

- 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 ITO AB2-188 Substation
- Because the generation interconnected is greater than 10 MW, the IC must provide generator status and generator instantaneous MW output to PJM per Manual 14A of the PJM OATT via communication links installed, owned, and maintained by the Customer.

In addition to the ITO facilities indicated above 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 ITO's Reclosers, AB2-188 Substation and IC's facility. The IC provided 34.5 kV 3-phase circuit will interconnect overhead at the Point of Interconnection which will be the load side terminals of the ITO provided pole mounted disconnect switch. 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.

The voltage and frequency set points, listed in Table 2, are derived from IEEE-1547a-2014 (Amendment to IEEE Standard 1547-2003). The "Total Clearing Time (sec)", listed in Table 2, is a summation of the detection time, field adjustable clearing time, and trip time. The IC will be required to apply all the enabled protection settings and not exceed the "Total Clearing Time (sec)".

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, ZVRT, and LFRT.

Function		Set Point	Total Clearing Time (sec)
			ITO
27	Under-voltage	V < 45% nominal voltage	0.160
		45% ≤ V < 60%	0.160
		60% ≤ V <88%	0.160
59	Over-voltage	110% < V < 120%	0.160
		V ≥ 120% nominal voltage	0.160
81U	Under-frequency	F < 57.0 Hz	0.160
		F < 59.5 Hz	0.160
81O	Over-frequency	F > 60.5 Hz	0.160
		F > 62.0 Hz	0.160
	Overall Anti-Islanding	Disconnect inverter from system (POI)	0.160
	Steady State Power Factor	Unity Power Factor	
LVRT	Low Voltage Ride Through	DISABLE	
HVRT	High Voltage Ride Through	DISABLE	
LFRT	Low Frequency Ride Through	DISABLE	
ZVRT	Zero Voltage Ride Through	DISABLE	

Table 1: IC Inverter Settings

Voltage Ride Through Requirements - The Customer Facility shall be designed to remain in service (not trip) for voltages and times as specified for the Eastern Interconnection in Attachment 1 of NERC Reliability Standard PRC-024-1, and successor Reliability Standards, for both high and low voltage conditions, irrespective of generator size, subject to the permissive trip exceptions established in PRC-024-1 (and successor Reliability Standards).

Frequency Ride Through Requirements - The Customer Facility shall be designed to remain in service (not trip) for frequencies and times as specified in Attachment 2 of NERC Reliability Standard PRC-024-1, and successor Reliability Standards, for both high and low frequency condition, irrespective of generator size, subject to the permissive trip exceptions established in PRC-024-1 (and successor Reliability Standards).

Reactive Power - The Generation Interconnection Customer shall design its non-synchronous Customer Facility with the ability to maintain a power factor of at least 0.95 leading to 0.95 lagging measured at the generator's terminals.

Meteorological Data Reporting Requirement - The solar generation facility shall, at a minimum, be required to provide the Transmission Provider with site-specific meteorological data including:

- Temperature (degrees Fahrenheit)
- Atmospheric pressure (hectopascals)
- Irradiance
- Forced outage data

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.

Interconnected Transmission Owner Requirements

Metering and SCADA/Communication equipment must meet the requirements outlined in section 3.1.6 Metering and Telecommunications of ITO's Facility Connection Requirement NERC Standard FAC-001 which is publically available at www.dom.com.

Network Impacts

The Queue Project AB2-188 was evaluated as a 20.0 MW (Capacity 13.8 MW) injection at Creswell 34.5kV substation in the ITO area. Project AB2-188 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AB2-188 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

Short Circuit

(Summary of impacted circuit breakers)

New circuit breakers found to be over-duty:

None

Contributions to previously identified circuit breakers found to be over-duty:

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

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

None

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

New System Reinforcements

(Upgrades required to mitigate reliability criteria violations, i.e. Network Impacts, initially caused by the addition of this interconnection request)

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 is calculated and reported for in 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 IC 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 interconnection request by addressing 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

Light Load Analysis in 2020

Not required

Affected System Analysis & Mitigation

Duke Energy:

None

Attachment 1.

System Configuration