Generation Interconnection
Combined System Impact / Facilities Study Report

For

PJM Generation Interconnection Request Queue Position AB1-135

Chickahominy 34.5kV
14MW Capacity / 20MW Energy

December / 2016

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 Charles City 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 Charles City, VA. The installed facilities will have a total capability of 20 MW with 14 MW of this output being recognized by PJM as capacity. The proposed in-service date for this project is 11/01/2016. **This study does not imply an ITO commitment to this in-service date.**

Point of Interconnection

AB1-135 will interconnect with the ITO distribution system via a tap onto a 34.5kV circuit fed out of Chickahominy Substation.

Cost Summary

The AB1-135 interconnection request will be responsible for the following costs:

Description	Total Cost
Attachment Facilities	$ 233,526
Direct Connection Network Upgrades	$6,655,003
Non Direct Connection Network Upgrades	$0
Allocation for New System Upgrades	$0
Contribution for Previously Identified Upgrades	$0
Total Costs	**$6,888,529**

Transmission Owner Scope of Work

The requested site will be connected to the ITO's 34.5 kV Circuit TBD out of Chickahominy Substation.

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 $233,526. 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 $233,526. The calculation will be $233,526 x 0.00543 = $1,268.05.

Local Nondirect Connection Cost Estimate

Complete the following activity regarding PJM Network Upgrade **n5168**. Install new 34.5kV circuit including getaway from Chickahominy Substation. Overbuild existing circuit for approximately 3,500 feet. Install new 34.5kV circuit along transmission ROW approximately 13,000 feet. Convert existing single phase to three phase and reconductor to 477AL for approximately 4,100 feet. Reconductor the existing circuit to 477AL approximately 20,700 feet to the IC site. Total estimated cost of the Engineering, Material, and Construction for all distribution upgrades equals $2,340,200. The estimated time for engineering, material acquisition and construction of this interconnection is 24 months.

Local Direct Connection Cost Estimate

Complete the following activity regarding PJM Network Upgrade **n5167**, expand Chickahominy Substation. The work includes the following:

- One (1), 230kV, 3000A center break horizontal mounted switch
- One (1), 230kV, 3000A Circuit Breaker
- One (1), 230–34.5kV, 33.6MVA, LTC, DY, Transformer
- Three (3), 180kV, MO, 144kV MCOV Station Class lightning Arresters
- Three (3), 30kV, MO, 24.4kV MCOV Station Class lightning Arresters
- One (1), 34.5kV, 3000A, 40kA, SF6 Circuit Breakers without relays

- One (1), 34.5kV, 1200A Aldi-Rupter load break switch
- Six (6), 34.5kV, 2000A Vertical Mounted Hook-stick Disconnects
- Two (2), 34.5kV, 1200A End-break switch
- Nine (9), 34.5kV, 1200A Hook-stick Disconnects
- Three (3), 27kV MO (DI), 22kV MCOV lightning Arresters
- Three (3), 34.5-kV, oil filled PT (300/175:1)
- Two (2), 34.5kV, 167KVA station service transformer
- 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 Eight (8), 23-kV, 12A current limiting fuse
- One (1), High Voltage Protection
- Steel structures and 3 ¼" x 3 ¼" x ¼" Aluminum angle as required to create 34.5kV bus
- Install conductor, connectors, conduit, control cable, foundations and grounding material as per engineering standards
- Install oil containment for one (1) transformer
- One (1), SEL 351 Breaker w/o reclosing Pnl
- One (1), SEL 387 Distribution TX Diff w/o L-Bkr Pnl
- One (1), SPR Relay/Auxiliary Package
- Two (2), SEL 2411 Equipment Annunciator
- Two (2), CB or Transformer Fiber MU Box
- One (1), SEL 311C Distribution Bus Pnl
- One (1), Three Phase Potential M.U. Box
- One (1), Single SEL 451 Circuit Pnl
- One (1), Station Service Potential M.U. Box
- One (1), 800A SS AC Distribution Pnl
- One (1), 225A outdoor Transmission AC NQOD
- One (1), 225amp Three Phase Throw over Switch
- One (1), 600amp Safety Switch
- One (1), Capcon Control (Cap SW) Box
- One (1), Cap bank C.T. M.U. Box
- One (1), SEL – 451-5 & SEL – 735 DG Support Panel (w/ Telco TT)
- One (1), DG Receiver Cabinet – AC [One Upline Recloser]

Total estimated cost of the Engineering, Material, and Construction for all substation upgrades equals $4,314,803. The estimated time for engineering, material acquisition and construction of this interconnection is 24 months.

Transmission Owner Technical Requirements

This is an inverter (UL1741/IEEE 1547 certified) based interconnection which consists of a total of seven (7) parallel blocks, with each parallel block consisting of two (2) parallel ABB Ultra

1500 TL inverters, each rated for 1,560kVA, operating at 690Vac. The two (2) parallel ABB Ultra 1500 TL inverters are interconnected via a dual primary / dual secondary three (3) phase 3,000kVA pad mounted transformer. All dual primary / dual secondary transformers will be rated 34.5/19.9kVac–690Vac with a wye-grounded (primary) – wye (secondary) winding configuration. At unity power factor, the inverter based interconnection has the capability of producing 21.84MVA. This generator shall be clipped at 20.0MVA (Unity Power Factor) operating at 690Vac. The resulting protection requirements are based on the following information:

- No more than 28.0MWdc / 20.0MVA 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 generation facility will be connected to the ITO system via a new POI Automatic Line Recloser (ALR) XXXRXX, sourced by a new ALR XXXRXX, new Chickahominy distribution feeder breaker XXX22, new Chickahominy 230/34.5kV 33MVA transformer.
- New Chickahominy 230/34.5kV 33MVA transfomrer has existing, or existing project queue generation totaling 20.0MWac, of which 20.00MWac is associated with this queue.
- New Chickahominy ALR XXXRXX will have reclosing times at 20 seconds and 55 seconds after the first trip.
- New Chickahominy distribution feeder breaker XXX22 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 Chickahominy ALR XXXRXX will have a typical "light" loading of 1.90MVA
  - New Chickahominy distribution feeder breaker XXX22 will have a typical "light" loading of 1.90MVA
  - New Chickahominy 230/34.5kV 33MVA TX will have a typical "light" loading of 1.90MVA

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

Utility Device	*Minimum Ratio*
New Chickahominy ALR XXXRXX	0.095
New Chickahominy distribution feeder breaker XXX22	0.095
New Chickahominy 230/34.5kV 33MVA TX	0.095

Table 1. Light Load to Generation Ratio

Based on the size and type of 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 (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 Vac) to this Power Monitor shall be supplied from a 2 kVA or larger Station Service (19.919 kV – 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.
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. The solar 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 generator 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 IC site recloser.

5. Station upgrades listed below are required (if not already existing) prior to parallel operations:

    a) Addition of standard 33MVA distribution transformer/bus protection relay panel to protect new 33MVA transformer and new 34.5kV bus.

    b) Addition of IC relay panel(SEL-451 and SEL-735). The SEL-451 is to be "keyed" by the existing 230kV Bus LOR.

    c) Install Direct Pilot Wire Tripping (or Transfer Trip) from each of the up-line ITO devices: New Chickahominy 230/34.5kV 33MVA TX, new Chickahominy 34.5kV bus, new Chickahominy distribution feeder breaker XXX22, new Chickahominy ALR XXXRXX to the IC site recloser

    d) Addition of standard microprocessor feeder protection relay panel for new Chickahominy distribution feeder.

Interconnection Customer Requirements

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

Interconnection Customer Responsibilities for 20 MW of Generation

- 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 IC breaker and ITO's Chickahominy 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 IC.

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, Chickahominy 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 (± 0.95 Control Range)	**Unity Power Factor**	
LVRT	Low Voltage Ride Through	DISABLE	
HVRT	High Voltage Ride Through	DISABLE	
ZVRT	Zero Voltage Ride Through	DISABLE	
LFRT	Low Frequency Ride Through	DISABLE	

Table 2: IC Inverter Settings

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
51P	Phase Time-delay Overcurrent	Set for minimum, with adequate load allowance	Maintain proper coordination with IC high side fuse
51G	Ground Time-Delay Overcurrent	Set above IC site cumulative transformers inrush current	Maintain proper coordination with upstream ground protection

32	Directional Power	Not to exceed IC power export in ISA	TBD

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.

Please promptly provide ITO details/confirmation concerning the IC's final inverter model (nameplate photos), the applied inverter trip points, and interface transformer specifications (i.e. transformer impedance, load losses, high side fuse make, model, rating, etc.).

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).

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 AB1-135 was evaluated as a 20.0 MW (Capacity 14.0 MW) injection at Chickahominy 230 kV station in the ITO area. Project AB1-135 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AB1-135 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Summer Peak Analysis - 2019

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 are performed for the Impact Study.)

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 2019

Not required

ITO Analysis

ITO assessed the impact of the proposed Queue Project #AB1-135 interconnection of 20 MW of energy (Capacity 14 MW) for compliance with reliability criteria on ITO's Transmission System. The system was assessed using the summer 2019 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 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 interconnection request 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 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):

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

Category C Analysis: (Multiple Facility Contingency)

- Bus Fault - No deficiencies identified
- Line Stuck Breaker - No deficiencies identified
- Tower Line – No deficiencies identified

As part of its generation impact analysis ITO routinely evaluates the impact that a proposed new generation resource (greater than 20 MW) will have under import/export system conditions. Since the proposed facility is less than 20 MW, no studies are required.

ITO's Planning Criteria indicates a need to have approximately 2000 MW of import and export capability. The results of these import and export studies indicate that the proposed AB1-135 will not impact ITO's import or export capability.

Affected System Analysis & Mitigation

Duke, Progress & TVA Impacts:

Duke Carolina, Progress, & TVA Impacts to be determined during later study phases (as applicable).

None identified

Attachment 1.

System Configuration