Generation Interconnection
System Impact Study Report

For

PJM Generation Interconnection Request
Queue Position AD1-105

Kings Dominion DP 115kV
44.4 MW Capacity / 74 MW Energy

Revision 2 / December 2021

Revision 1 / November 2021

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 Invenergy Solar Development North America 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.

Revision 2 Summary

This revision is being issued to enhance the detail on the transmission level work required. This detail was provided in the Transmission Owner Scope of Work section.

Revision 1 Summary

This revision is being issued due to a re-tool that was performed. The report is being updated to reflect the results of the re-tool and changes to required system upgrades.

General

The IC has proposed a solar generating facility located in Enfield, VA (King William County). The installed facilities will have a total capability of 74 MW with 44.4 MW of this output being recognized by PJM as capacity. The proposed in-service date for this project is 12/31/2023.
This study does not imply an ITO commitment to this in-service date.

Point of Interconnection

AD1-105 will interconnect with the ITO transmission system via ITO King Dominion DP 115kV tap which feeds Rappahannock Electrical Cooperative's system.

Cost Summary

The AD1-105 project will be responsible for the following costs:

Description	Total Cost
Attachment Facilities	$Cost to be provided in separate Agreement between IC, Dominion and REC
Direct Connection Network Upgrades	$Cost to be provided in separate Agreement between IC, Dominion and REC
Non Direct Connection Network Upgrades	$Cost to be provided in separate Agreement between IC, Dominion and REC
Allocation for New System Upgrades	$0
Contribution for Previously Identified Upgrades	$0
Total Costs	**$0 +$Cost to be provided in separate Agreement between IC, Dominion and REC**

Transmission Owner Scope of Work

The required Direct Connection and Non-Direct Connection work for the interconnection of AD1-105 to the Dominion Transmission System is detailed in the following sections. The associated one-line showing the generation project and primary direct and non-direct connection is shown in Attachment 1.

Attachment facilities and local upgrades (if required) along with terms and conditions to interconnect AD1-105 will be specified in a separate three party Interconnection Agreement (IA) between Rappahannock Electrical Co-operative, Dominion and the IC as this project is considered FERC non-jurisdictional per the PJM Open Access Transmission Tariff (OATT).

Remote Terminal Work: As part of the separate three party Interconnection Agreement (IA), ITO's System Protection Engineering Department will review transmission line protection as well as anti-islanding required to accommodate the new generation and interconnection substation. System Protection Engineering will determine the minimal acceptable protection requirements to reliably interconnect the proposed generating facility with the transmission system. The review is based on maintaining system reliability by reviewing ITO's protection requirements with the known transmission system configuration which includes generating facilities in the area. This review may determine that transmission line protection and communication upgrades are required at remote substations.

The total physical interconnection costs are given in the table below:

Description	Total Cost
Rebuild Kings Dominion DP 115 kV substation to Three Breaker Ring-Bus Substation	$ Costs to be determined in separate agreement with Dominion, Interconnection Customer and Rappahannock Electric Cooperative.
Re-arrange line and tie-in new substation	$ Costs to be determined in separate agreement with Dominion, Interconnection Customer and Rappahannock Electric Cooperative.
Total Physical Interconnection Costs	**$ Costs to be determined in separate agreement with Dominion, Interconnection Customer and Rappahannock Electric Cooperative.**

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

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 AD1-105 was evaluated as a 74.0 MW (Capacity 44.4 MW). AD1-105 will interconnect with the ITO transmission system via ITO King Dominion DP 115kV tap in the VAP area. Project AD1-105 was evaluated for compliance with applicable reliability planning criteria (PJM, NERC, NERC Regional Reliability Councils, and Transmission Owners). Project AD1-105 was studied with a commercial probability of 100%. Potential network impacts were as follows:

Contingency Descriptions

The following contingencies resulted in overloads:

Contingency Name	Description
DVP_P1-2: LN 2032	CONTINGENCY 'DVP_P1-2: LN 2032' OPEN BRANCH FROM BUS 314212 TO BUS 314222 CKT 1 /* 6FRRIVER 230.00 - 6HANOVER 230.00 OPEN BRANCH FROM BUS 314218 TO BUS 314222 CKT 1 /* 6ELMONT 230.00 - 6HANOVER 230.00 OPEN BUS 314222 /* ISLAND END
DVP_P1-2: LN 2032	CONTINGENCY 'DVP_P1-2: LN 2032' OPEN BRANCH FROM BUS 314212 TO BUS 314222 CKT 1 /* 6FRRIVER 230.00 - 6HANOVER 230.00 OPEN BRANCH FROM BUS 314218 TO BUS 314222 CKT 1 /* 6ELMONT 230.00 - 6HANOVER 230.00 OPEN BUS 314222 /* ISLAND END
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Summer Peak Analysis – 2021

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)

#	Contingency Type	Contingency Name	Affected Area	Facility Description	Bus From	Bus To	Cir.	Power Flow	Loading % Initial	Loading % Final	Rating Type	Rating MVA	MW Contribution	Ref
1	N-1	DVP_P1-2: LN 2032	DVP - DVP	6STJOHN-6LDYSMITH CT 230 kV line	314150	314197	1	AC	105.36	110.05	ER	899	44.17	1
2	N-1	DVP_P1-2: LN 2032	DVP - DVP	8LADYSMITH 500/230 kV transformer	314196	314911	1	AC	106.52	110.01	ER	848	29.04	2

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)

Based on the Impact Study data provided, the reactive power capability of AD1-105 does NOT meet the 0.95 lagging PF requirement, whereas 0.95 leading PF requirement was met at the high side of the main transformer. Please see Attachment 2 for Stability Study Executive Summary.

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)

Violation #	Overloaded Facility	Upgrade Description	Network Upgrade Number	Upgrade Cost	AD1-105 Allocation
# 1	6STJOHN-6LDYSMITH CT 230 kV line	Four Rivers – St. Johns 230kV line # 256 wave trap at Four Rivers and line switches at St. Johns replaced. Work completed in 2017 and new rating of 876 MVA (normal), 956 MVA (emergency) and 1163 MVA (load dump). Please note, this upgrade is already in-service	N4692	$0	**$0**
# 2, 3	8LADYSMITH 500/230 kV transformer	Add a second Ladysmith 500/230kV transformer with a rating of 840MVA. Work is estimated to be completed by 6/01/2021. Please note, this upgrade is already in-service	b3027.1	$0	**NA**
				Total New Network Upgrades	**$0**

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.

	Contingency		Affected		Bus			Power	Loading %		Rating		MW
#	Type	Name	Area	Facility Description	From	To	Circuit	Flow	Initial	Final	Type	MVA	Contribution
3	N-1	DVP_P1-2: LN 2032	DVP - DVP	6STJOHN-6LDYSMITH CT 230 kV line	314150	314197	1	AC	105.37	113.33	ER	899	73.62
4	N-1	DVP_P1-2: LN 2032	DVP - DVP	8LADYSMITH 500/230 kV transformer	314196	314911	1	AC	105.75	111.65	ER	848	48.4

Light Load Analysis in 2021

Not required

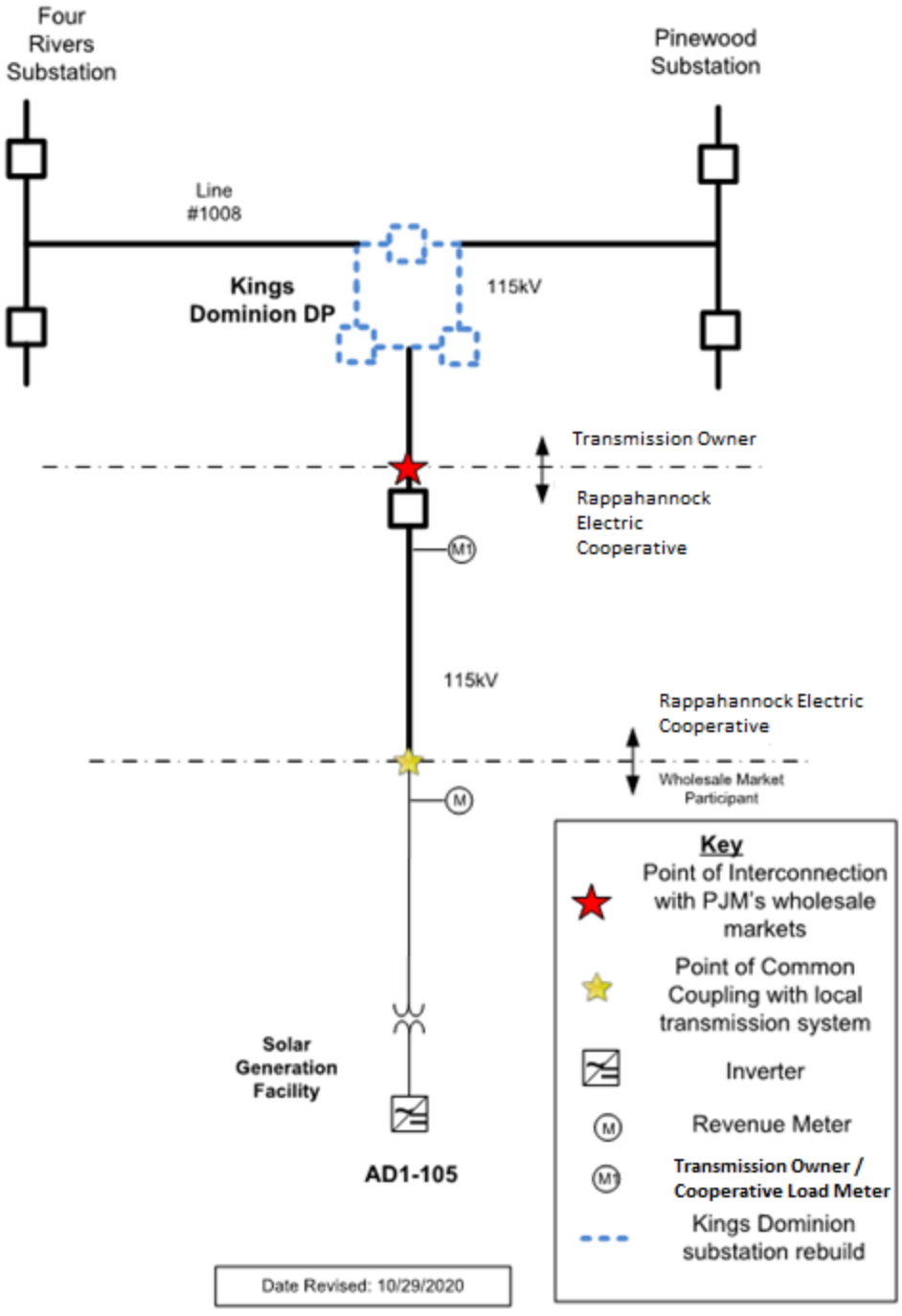
Affected System Analysis & Mitigation

Duke Energy:

None

Attachment 1.

System Configuration



Attachment 2- Stability Study Executive Summary

Generator Interconnection Request AD1-105 is for a 77 MW Maximum Facility Output (MFO) solar generation plant. AD1-105 consists of 27 x Power Electronics FS3000 inverters rated to 2.88 MW each. AD1-105 has a Point of Interconnection (POI) at the existing Enfield 115 kV substation in the Dominion Virginia Power (DVP) System, King William County, Virginia.

This report describes a dynamic simulation analysis of AD1-105 as part of the overall system impact study.

The loadflow scenario for the analysis was based on the RTEP 2021 peak load case, modified to include applicable queue projects. AD1-105 has been dispatched online at maximum power output, with 1.0 p.u. voltage at the generator bus.

AD1-105 was tested for compliance with NERC, PJM, Transmission Owner and other applicable criteria. Steady-state condition and 36 contingencies were studied, each with at least a 20 second simulation time period. Studied faults included:

a) Steady-state operation (30 second),

b) Three-phase faults with normal clearing time,

c) Single-phase bus faults,

d) Single-phase faults with stuck breaker,

e) Single-phase faults placed at 80% of the line with delayed (Zone 2) clearing at line end remote from the fault due to primary communications/relay failure,

f) Single-phase faults with loss of multiple-circuit tower line.

No bus high-speed reclosing (HSR) contingencies were identified for this study.

For all simulations, the queue project under study along with the rest of the PJM system were required to maintain synchronism and with all states returning to an acceptable new condition following the disturbance.

The frequency relays of AD1-105 were disabled to resolve the tripping issue of the queue project in contingencies P1.01, P1.02 and P1.03 due to the fictitious frequency response.

In the VTGDCAT relay model for low voltage protections of AD1-105, the time delay for MINS 93478407 was changed to 0.5 seconds from 0.3 seconds to resolve under voltage tripping issue in contingencies P4.11 and P4.12.

For all of the fault contingencies tested on the 2021 peak load case:

a) AD1-105 was able to ride through the faults (except for faults where protective action trips a generator(s));

b) Post-contingency oscillations were positively damped with a damping margin of at least 3% for interarea modes and 4% for local modes;

c) Following fault clearing, all bus voltages recovered to a minimum of 0.7 per unit after 2.5 seconds (except where protective action isolates that bus);

d) No transmission element tripped, other than those either directly connected or designed to trip as a consequence of that fault.

Based on the Impact Study data provided, the reactive power capability of AD1-105 does NOT meet the 0.95 lagging PF requirement, whereas 0.95 leading PF requirement was met at the high side of the main transformer.

No mitigations were found to be required.

Appendices

The following appendices contain additional information about each flowgate presented in the body of the report. For each appendix, a description of the flowgate and its contingency was included for convenience. However, the intent of the appendix section is to provide more information on which projects/generators have contributions to the flowgate in question. All New Service Queue Requests, through the end of the Queue under study, that are contributors to a flowgate will be listed in the Appendices. Please note that there may be contributors that are subsequently queued after the queue under study that are not listed in the Appendices. Although this information is not used "as is" for cost allocation purposes, it can be used to gage the impact of other projects/generators.

It should be noted the project/generator MW contributions presented in the body of the report and appendices sections are full contributions, whereas the loading percentages reported in the body of the report, take into consideration the commercial probability of each project as well as the ramping impact of "Adder" contributions.

Appendix 1

(DVP - DVP) The 6STJOHN-6LDYSMITH CT 230 kV line (from bus 314150 to bus 314197 ckt 1) loads from 105.36% to 110.05% (AC power flow) of its emergency rating (899 MVA) for the single line contingency outage of 'DVP_P1-2: LN 2032'. This project contributes approximately 44.17 MW to the thermal violation.

Bus Number	*Bus Name*	*Full Contribution*
315043	*1FOUR RIVERA*	*20.78*
315044	*1FOUR RIVERB*	*16.07*
315045	*1FOUR RIVERC*	*20.78*
315046	*1FOUR RIVERD*	*16.07*
315047	*1FOUR RIVERE*	*16.07*
315048	*1FOUR RIVERF*	*20.78*
934781	*AD1-105 C*	*44.17*
LTF	*AMIL*	*0.15*
LTF	*BLUEG*	*0.89*
LTF	*CALDERWOOD*	*0.28*
LTF	*CANNELTON*	*0.16*
LTF	*CARR*	*0.19*
LTF	*CATAWBA*	*0.18*
LTF	*CHEOAH*	*0.25*
LTF	*CLIFTY*	*3.66*
LTF	*COTTONWOOD*	*1.07*
LTF	*EDWARDS*	*0.27*
LTF	*ELMERSMITH*	*0.45*
LTF	*FARMERCITY*	*0.18*
LTF	*GIBSON*	*0.3*
LTF	*HAMLET*	*0.29*

LTF	*MORGAN*	*0.89*
LTF	*NEWTON*	*0.68*
LTF	*PRAIRIE*	*1.31*
LTF	*RENSSELAER*	*0.15*
LTF	*SMITHLAND*	*0.11*
LTF	*TATANKA*	*0.32*
LTF	*TILTON*	*0.32*
LTF	*TRIMBLE*	*0.17*
LTF	*TVA*	*0.4*
LTF	*UNIONPOWER*	*0.4*
918691	*AA1-083*	*3.65*
919211	*AA1-145*	*62.02*
924061	*AB2-050*	*3.65*
926551	*AC1-134*	*49.75*

Appendix 2

(DVP - DVP) The 8LADYSMITH 500/230 kV transformer (from bus 314196 to bus 314911 ckt 1) loads from 106.52% to 110.01% (AC power flow) of its emergency rating (848 MVA) for the single line contingency outage of 'DVP_P1-2: LN 2032'. This project contributes approximately 29.04 MW to the thermal violation.

Bus Number	*Bus Name*	*Full Contribution*
315033	*1BIRCHWDA*	*14.16*
315043	*1FOUR RIVERA*	*13.66*
315044	*1FOUR RIVERB*	*10.56*
315045	*1FOUR RIVERC*	*13.66*
315046	*1FOUR RIVERD*	*10.56*
315047	*1FOUR RIVERE*	*10.56*
315048	*1FOUR RIVERF*	*13.66*
315037	*1LDYSMT1*	*18.12*
315038	*1LDYSMT2*	*18.11*
315039	*1LDYSMT3*	*19.16*
315040	*1LDYSMT4*	*19.2*
315041	*1LDYSMT5*	*19.26*
315034	*1NORNECKC1*	*0.58*
315035	*1NORNECKC2*	*0.56*
315005	*1POSSM 3*	*2.*
314131	*6ARNOLDS*	*0.53*
314134	*6CRANES*	*0.12*
933011	*AC2-125*	*9.74*
933021	*AC2-126*	*9.81*

933271	*AC2-138 C*	*0.11*
934781	*AD1-105 C*	*29.04*
LTF	*AMIL*	*0.3*
LTF	*BLUEG*	*1.8*
LTF	*CALDERWOOD*	*0.64*
LTF	*CANNELTON*	*0.32*
LTF	*CARR*	*0.2*
LTF	*CATAWBA*	*0.45*
LTF	*CHEOAH*	*0.58*
LTF	*CLIFTY*	*7.3*
LTF	*COTTONWOOD*	*2.35*
LTF	*EDWARDS*	*0.54*
LTF	*ELMERSMITH*	*0.91*
LTF	*FARMERCITY*	*0.37*
LTF	*GIBSON*	*0.61*
LTF	*HAMLET*	*0.76*
LTF	*MORGAN*	*1.99*
LTF	*NEWTON*	*1.39*
LTF	*PRAIRIE*	*2.73*
LTF	*RENSSELAER*	*0.15*
LTF	*SMITHLAND*	*0.22*
LTF	*TATANKA*	*0.66*
LTF	*TILTON*	*0.64*
LTF	*TRIMBLE*	*0.34*
LTF	*TVA*	*0.87*
LTF	*UNIONPOWER*	*0.93*

918691	*AA1-083*	*2.4*
919211	*AA1-145*	*40.76*
924061	*AB2-050*	*2.4*
926471	*AC1-118 C*	*0.43*
926551	*AC1-134*	*32.7*