2012 NCTPC – PJM Joint Interregional Reliability Study

PJM Interconnection

Duke Energy Carolinas

Progress Energy Carolinas

January 2013

Executive Summary

The joint study consisted of a reliability analysis of the PJM Interconnection and North Carolina Transmission Planning Collaborative (NCTPC) footprint to assess the interaction of hypothetical off-shore wind injections in PJM and Progress Energy Carolinas (PEC). The NCTPC footprint is comprised of the Duke Energy Carolinas (DEC) and PEC balancing areas. The study information presented here examines three scenarios of wind penetration into the PJM, DEC and PEC systems and varying levels of power transfer between the systems. The study evaluated potential thermal constraints to wind penetration and proposes network upgrades to mitigate identified constraints in each scenario.

The reliability analysis consisted of N-1 thermal analysis of each scenario to identify potential system constraints. The scenarios modeled wind penetration at injection points ranging from 1,000 MW to 4,500 MW at PJM's Landstown 230 kV substation, 1,000 MW to 3,500 MW in PEC's Morehead City 230 kV substation area, and 1,000 MW to 2,000 MW in PEC's Southport 230 kV substation area. Power transfers between study areas were modeled in each scenario to simulate the delivery of wind power from the injection points to the adjacent system. Network upgrades were proposed to mitigate identified constraints for each scenario and strengthen the system to support wind power injection and power transfers between systems.

The analysis showed PJM's Landstown 230 kV substation is capable of handling wind injections up to 2,000 MW without major upgrades due to the strength of the local transmission system. Wind penetration greater than 4,500 MW at the Landstown 230 kV substation would require interconnection to the 500 kV network via a new Landstown 500 kV substation, as well as upgrades to the 500 kV system and local 230 kV network. PEC's injection points were not capable of handling the levels of injection in the study and required new transmission in order to

transmit the power to stronger inland transmission buses for all levels of the study. Any issues identified in the DEC system were driven by the level of import rather than the magnitude of the wind injection and did not require major network upgrades.

Integration of 3,000 – 10,000 MW of off-shore wind in North Carolina and Virginia would require approximately $1-2 billion in transmission upgrades. Details of the required upgrades and cost estimates are provided in Section 7.0. Detailed interconnection analysis of the studied systems would be required to reveal the full extent of necessary network improvements but the analysis provided in this report is indicative of how the studied systems would respond to large amounts of wind penetration at off-peak load conditions.

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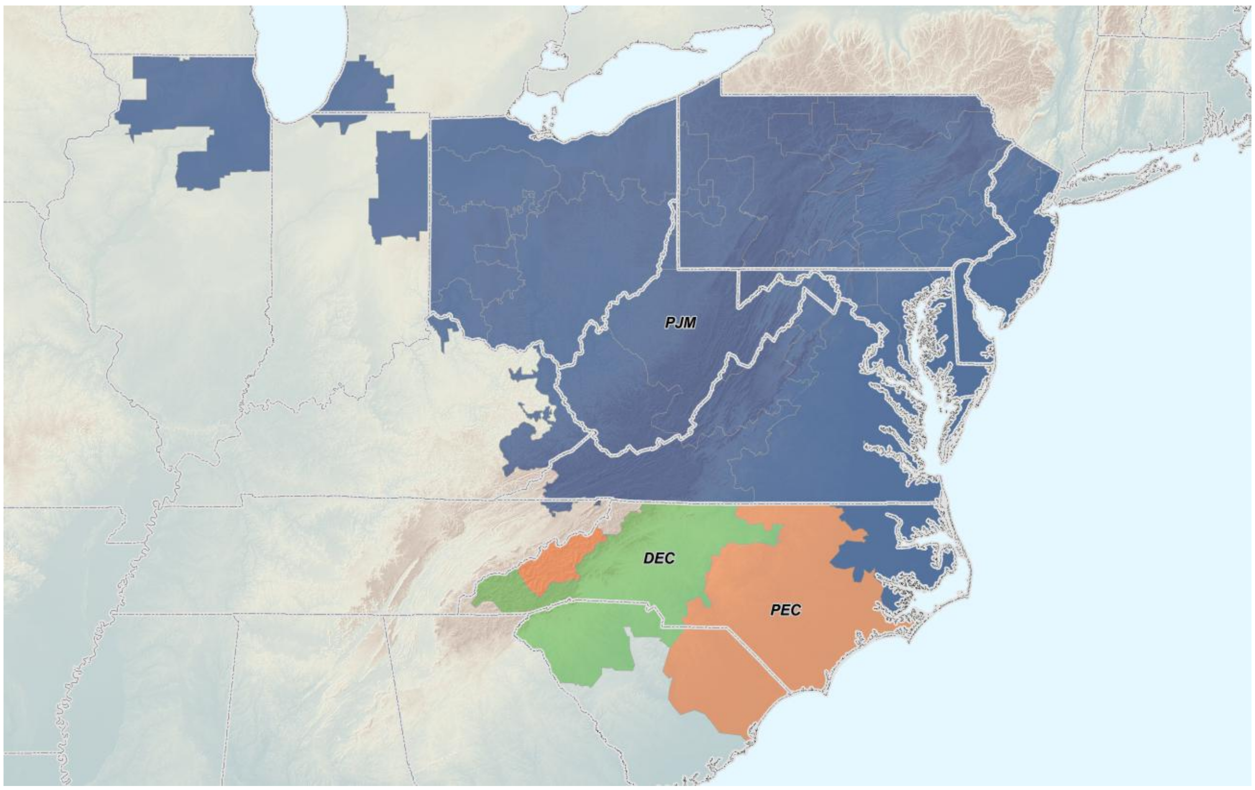
1.0 Introduction/Background

The joint study consisted of a reliability analysis of the PJM Interconnection and North Carolina Transmission Planning Collaborative (NCTPC) footprint to assess the interaction of off-shore wind injections into PJM and Progress Energy Carolinas (PEC). The NCTPC footprint is comprised of the Duke Energy Carolinas (DEC) and PEC control areas.

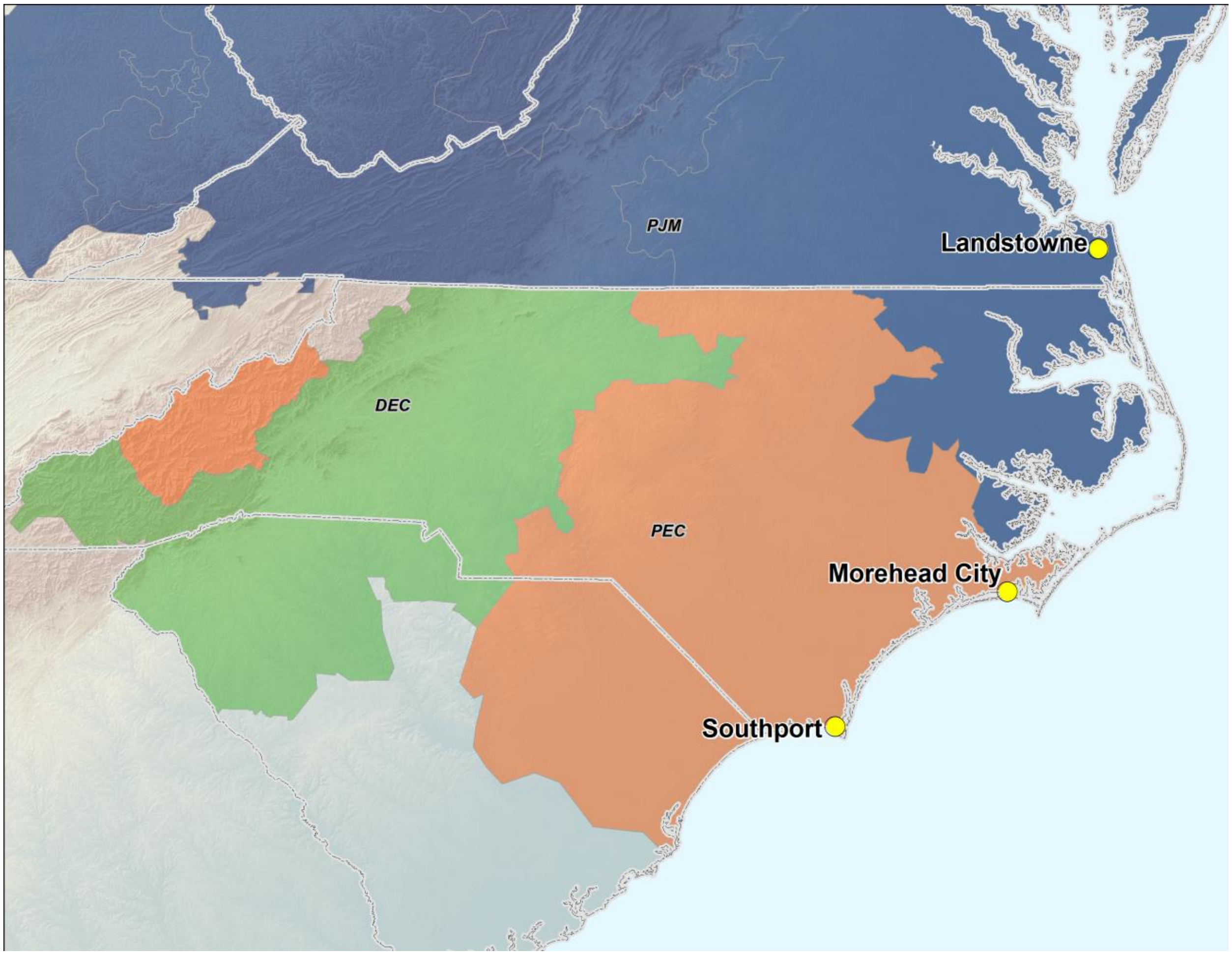
Figure 1 - Map of PJM, DEC and PEC Control Areas



The goals of the analysis were to identify potential thermal constraints to wind penetration and to propose network reinforcements to mitigate identified constraints. The study evaluated wind penetration at three off-shore injection points: Dominion's Landstown 230 kV substation, PEC's Morehead City 230 kV substation and PEC's Southport 230 kV substation (see

Figure 2). Three different scenarios were evaluated with varying levels of wind penetration and varying levels of power transfer between the PJM, DEC and PEC systems.

Figure 2 - Location of Wind Injection Points



2.0 Base Case Development

A 2027 off-peak base case was developed as the starting point model and was used to develop three scenario cases for the reliability analysis. Off-peak load study conditions were chosen to coincide with the more favorable conditions for wind resource output. Wind resources typically experience higher production during off-peak or overnight hours when weather conditions are windier than during on-peak periods. The load level of each study area was set to 60% of 2027 summer forecasted peak levels and generation was economically dispatched to satisfy load and interchange requirements. The interchange between study participants was established in accordance with long-term firm transmission service requests which can be found in Appendix A.

The most recent available internal planning models of study participants were incorporated into the 2027 off-peak base case. PJM's system topology was representative of the 2017 Regional Transmission Expansion Plan (RTEP) Summer Peak Model which included all 2012 RTEP approved upgrades at the time the model was created. DEC and PEC system topology reflected their internal 2022 summer peak case. DEC and PEC merger projects were included in the base case. The external system topologies were based on the 2011 MMWG Series.

PJM generation reflected existing units, queue project units which have a signed ISA or FSA, and all deactivation requests made by the end of the April 2012. DEC and PEC generation reflected existing units, projected unit retirements, and queue projects units which have a signed LGIA by the end of the May 2012. No new generation expected to be in-service after 2017 was added to the base case.

Prior to evaluating the impact of the wind injections, the 2027 off-peak case was screened for base thermal overloads and voltage violations. Base case issues were identified and mitigated with non-topology changes such as generation re-dispatch, the adjustment of capacitor banks or rating corrections.

3.0 Scenario and Transmission Development

Three scenario cases were developed from the 2027 off-peak base case to represent different interactions between the study areas. Each scenario case modeled a different amount of wind penetration at each of the injection points. The analysis assumed an injection amount at the study's wind injection points and system upgrades were designed based on that assumption. The assumption served the purpose of ensuring the wind resource would not be subject to curtailment due to transmission system constraints. Power transfers between the study areas were modeled in each scenario to simulate the delivery of wind power from the injection points to an adjacent system. Power transfers were implemented on top of the base case interchanges.

Wind penetration at the injection points could potentially impact the network under normal conditions (no contingency outages). Network reinforcements were modeled in the vicinity of the injection points prior to conducting the N-1 reliability analysis in anticipation of these needs. For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need. If reinforcements were not added to a scenario it implied that under normal conditions the transmission system could accommodate the injection with no additional infrastructure. Other network upgrades, such as ancillary equipment upgrades or additional transmission lines, may have been modeled to reinforce the network.

The analysis in this report assumes that the hypothetical wind generation, at three locations, is delivered to local onshore substations. For PJM, the wind generation was integrated at Dominion's Landstown 230 kV substation. For PEC, the Morehead City 230 kV substation and the Southport 230 kV substation were not capable of accepting the large amounts of generation. A new Morehead 500 kV switching station was included along with two 500 kV lines, each 40 miles long, connecting it to PEC's existing Jacksonville substation. Similarly, a new Southport 500 kV switching station was included along with two 500 kV lines, each 30 miles long, connecting it to a new PEC Sutton North 500 kV substation. The Sutton North substation was formed by looping-in three existing 230 kV transmission lines and adding 500/230 kV transformation. Having to transmit the wind generation to stronger inland transmission buses on the PEC system added substantial transmission costs to the estimates.

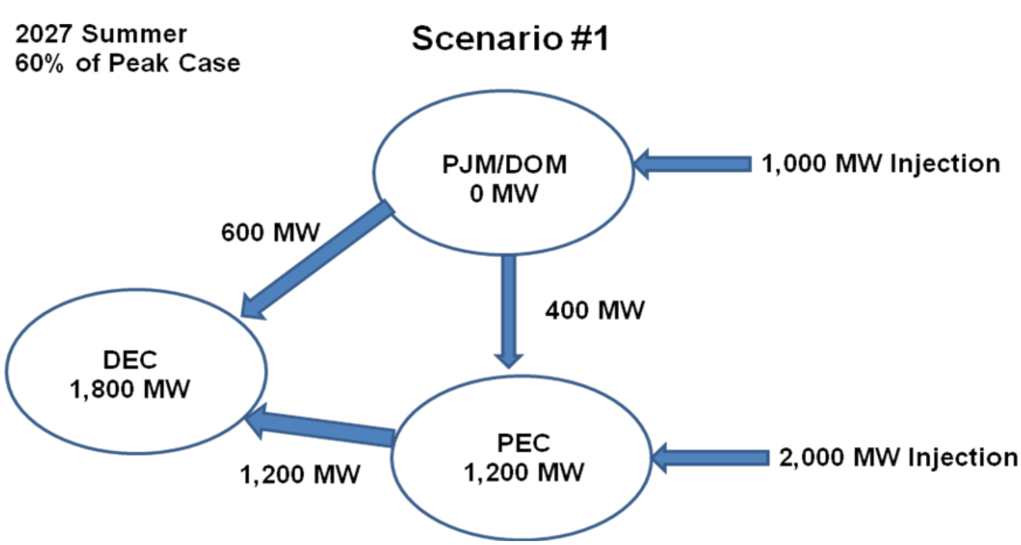
3.1 Scenario 1 Development

The following table summarizes the wind injection amounts and respective sink area amounts for Scenario 1:

Table 1 - Summary of Scenario 1 Wind Injection and Area Transfers

Injection Point	PJM (sink)	DEC (sink)	PEC (sink)
PJM – 1,000 MW injection at Landstown	0 MW 0%	600 MW 60%	400 MW 40%
NCTPC – 1,000 MW injection at Morehead City	0 MW 0%	600 MW 60%	400 MW 40%
NCTPC – 1,000 MW injection at Southport	0 MW 0%	600 MW 60%	400 MW 40%
Total	0 MW	1,800 MW	1,200 MW

Scenario 1 modeled a total of 3,000 MW of wind injection into the PJM and PEC systems. A total of 1,800 MW (60%) was sunk into the DEC system and 1,200 MW (40%) was sunk into the PEC system. A 600 MW transfer from PJM to DEC and a 400 MW transfer from PJM to PEC were modeled to simulate the power sinking into the DEC and PEC systems. A 1,200 MW transfer from PEC to DEC was modeled to satisfy the remaining power sinking in the DEC system.



There were no DEC or PJM network reinforcements added during Scenario 1 case development. For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need. A listing of these upgrades is provided in Section 7.0, Table 7.

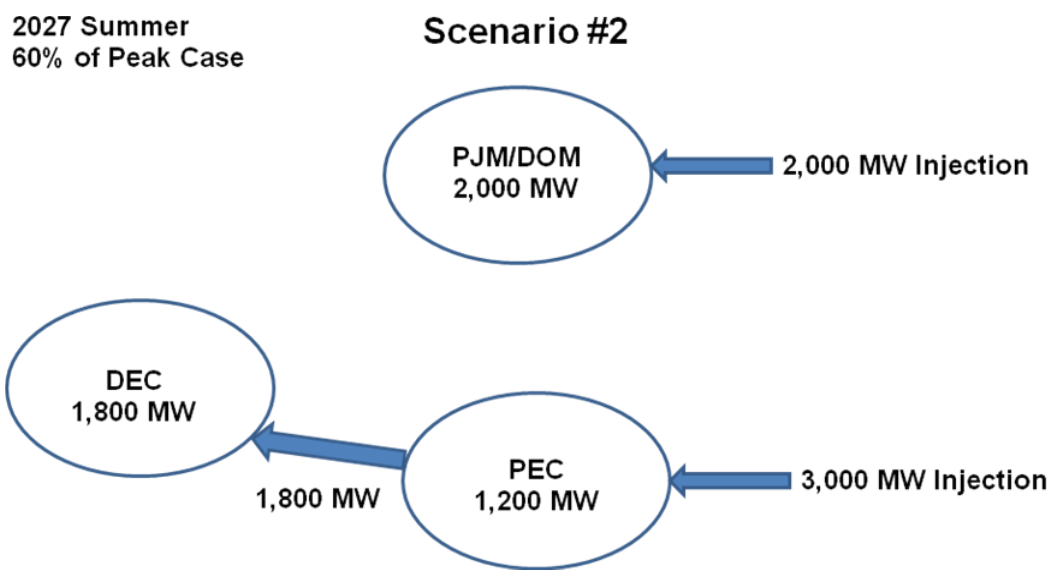
3.2 Scenario 2 Development

The following table summarizes the wind injection amounts and respective sink area amounts for Scenario 2:

Table 2 - Summary of Scenario 2 Wind Injection and Area Transfers

Injection Point	PJM (sink)	DEC (sink)	PEC (sink)
PJM – 2,000 MW injection at Landstown	2,000 MW 100%	0 MW 0%	0 MW 0%
NCTPC – 1,500 MW injection at Morehead City	0 MW 0%	900 MW 60%	600 MW 40%
NCTPC –1,500 MW injection at Southport	0 MW 0%	900 MW 60%	600 MW 40%
Total	2,000 MW	1,800 MW	1,200 MW

Scenario 2 modeled a total of 5,000 MW of wind injection into the PJM and PEC systems. A total of 2,000 MW (40%) was sunk into the PJM system and was satisfied by the wind injection at Landstown. A total of 1,800 MW (36%) was sunk into the DEC system and 1,200 MW (24%) was sunk into the PEC system. A 1,800 MW transfer from PEC to DEC was modeled to simulate the power sinking in the DEC system.



There were no DEC or PJM network reinforcements added during Scenario 2 case development. For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need. A listing of these upgrades is provided in Section 7.0, Table 8.

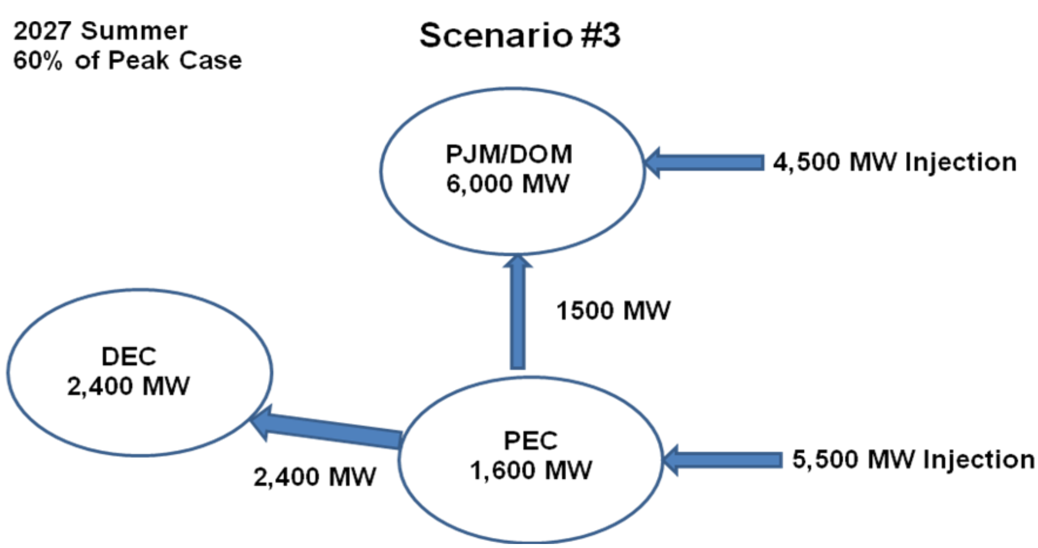
3.3 Scenario 3 Development

The following table summarizes the wind injection amounts and respective sink area amounts for Scenario 3:

Table 3 - Summary of Scenario 3 Wind Injection and Area Transfers

Injection Point	PJM (sink)	DEC (sink)	PEC (sink)
PJM –4,500 MW injection at Landstown	4,500 MW 100%	0 MW 0%	0 MW 0%
NCTPC –3,500 MW injection at Morehead City	950 MW 27.3%	1,500 MW 43.6%	1,000 MW 29.1%
NCTPC –2,000 MW injection at Southport	550 MW 27.3%	900 MW 43.6%	600 MW 29.1%
Total	6000 MW	2,400 MW	1,600 MW

Scenario 3 modeled a total of 10,000 MW of wind injection into the PJM and PEC systems. A total of 6,000 MW (60%) was sunk into the PJM system and was satisfied by the wind injection at Landstown with an additional transfer of 1,500 MW from PEC to PJM. A total of 2,400 MW (24%) was sunk into the DEC system and 1,600 MW (16%) was sunk into the PEC system. A 2,400 MW transfer from PEC to DEC was modeled to simulate the power sinking in the DEC system.



There were no network reinforcements added to the DEC system in the Scenario 3 case development. The following network reinforcements were added to the PJM system during Scenario 3 case development:

- New Landstown 500 kV bus and wind injection moved from 230 kV bus to new bus
- Two new Landstown 500/230 kV transformers
- New Landstown – Yadkin 500 kV line
- 2nd Landstown – Fentress 230 kV line
- 2nd Fentress – Thrasher 230 kV line
- 2nd Landstown – Stumpy Lake 230 kV line
- 2nd Stumpy Lake – Thrasher 230 kV line

For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need. A listing of these upgrades is provided in Section 7.0, Table 9.

4.0 Monitor, Subsystem and Contingency Files

The monitor file was assigned to monitor bulk electric system elements, 100 kV and above, for facilities in PJM, DEC and PEC as well as areas surrounding the common interfaces between the systems. The subsystem file was used to define the area subsystems which would be monitored in conjunction with the monitor file. The single contingency file used for the analysis was derived from each study participant's contingency files for its own internal planning analysis. The contingency file was screened for contingencies at or above 100 kV.

5.0 Method of Analysis

A thermal N-1 analysis was conducted on each of the scenario cases to test the post-contingency reliability of the network. The reliability analysis was conducted using the Siemens PSS/E Version 32 analysis software. The results were reported as a network element, a single contingency and the thermal loading on the element due to that respective contingency. Results were reported and reviewed to determine which overloads would require additional reinforcements to the network.

Violations in each scenario case were addressed independently from the next scenario. Solutions were determined, modeled in the scenario case and then verified to ensure the solutions were effective. Any proposed solution could potentially mitigate either a single identified violation or multiple violations.

The analysis was a general reliability screening of NERC criteria intended to be indicative of the system capability to perform under the specific study conditions. PJM, DEC and PEC would require a detailed internal analysis based on their individual criteria to reveal any additional system vulnerabilities.

6.0 N-1 Thermal Scenario Analysis

6.1 Scenario 1 Analysis Results

N-1 thermal violations were identified in the DEC system for the Scenario 1 analysis, shown below in Table 4:

Table 4 - Scenario 1 Case – N-1 Thermal Violations

FROM	NAME	TO	NAME	KV	CKT	AREA	CONTINGENCY	RATE A/B	% FLOW
306334	Peacock Tie	306332	Catawba Nuclear Station	230	1	DEC	PEACOCKB	320.00	129.82
308334	Peacock Tie	306332	Catawba Nuclear Station	230	2	DEC	PEACOCKW	320.00	129.82
CONTINGENCY DEFINITION									
PEACOCKB: Loss of Catawba - Peacock 230 kV Ckt. 2									
PEACOCKW: Loss of Catawba - Peacock 230 kV Ckt. 1									

For the loss of the parallel line, the remaining 230 kV line between DEC's Catawba Nuclear Station and Peacock Tie may become overloaded. Ancillary equipment upgrades may be performed in order to utilize the full conductor rating of the line.

There were no N-1 thermal violations identified in the PEC and PJM systems for Scenario 1.

6.2 Scenario 2 Analysis Results

N-1 thermal violations were identified in the DEC, PEC and PJM systems for the Scenario 2 analysis, shown below in Table 5:

Table 5 - Scenario 2 Case – N-1 Thermal Violations

		BRANCH							
FROM	NAME	TO	NAME	KV	CKT	AREA	CONTINGENCY	RATE A/B	% FLOW
306334	Peacock Tie	306332	Catawba Nuclear Station	230	1	DEC	PEACOCKB	320.00	130.26
308334	Peacock Tie	306332	Catawba Nuclear Station	230	2	DEC	PEACOCKW	320.00	130.26
314502	Stumpy Lake 230 kV	314481	Landstown 230 kV	230	1	PJM	LN 271	719.00	126.48
304485	Havelock 115	304473	3PA-NBCITY#5	115	1	CPLE	JAX-TARAWA23	208.00	119.29
306543	Riverbend Steam Station	306540	McGuire Nuclear Station	230	1	DEC	NORMANB	557.00	117.55
308543	Riverbend Steam Station	306540	McGuire Nuclear Station	230	2	DEC	NORMANW	557.00	117.37
304473	3PA-NBCITY#5	304467	Amital Tap 115 kV	115	1	CPLE	JAX-TARAWA23	208.00	116.42
304466	New Bern 115 kV	304467	Amital Tap 115	115	1	CPLE	JAX-TARAWA23	208.00	114.90
314481	Landstown 230 kV	314486	Lynhaven 230 kV	230	1	PJM	6LANDSTN_6ST	637.00	105.15
305004	EMC Prospect 230 kV	304020	Brunswick #2 Plant 230 k	230	1	CPLE	GRNVL-CHOCWN	557.00	100.12
CONTINGENCY DEFINITION									
PEACOCKB: Loss of Catawba - Peackcock 230 kV Ckt. 2									
PEACOCKW: Loss of Catawba - Peacock 230 kV Ckt. 1									
LN 271: Loss of Landstown - Fentress 230 kV Ckt. 1									
JAX-TARAWA23: Loss of Jacksonville - Northwood 115 kV Ckt. 1 and loss of Jacksonville - Camp Lejeune Tap 230 kV Ckt. 1									
NORMANB: Loss of McGuire - Riverbend 230 kV Ckt. 2									
NORMANW: Loss of McGuire - Riverbend 230 kV Ckt. 1									
JAX-TARAWA23: Loss of Jacksonville - Northwood 115 kV Ckt. 1 and loss of Jacksonville - Camp Lejeune Tap 230 kV Ckt. 1									
JAX-TARAWA23: Loss of Jacksonville - Northwood 115 kV Ckt. 1 and loss of Jacksonville - Camp Lejeune Tap 230 kV Ckt. 1									
6LANDSTN_6ST: Loss of Landstown - Stumpy 230 kV Ckt. 1									
GRNVL-CHOCWN: Loss of PA-Greenville - Chocowinity 230 kV Ct. 1 and PA-Greenville - Everetts 230 kV Ckt. 1									

For the loss of the parallel line, the remaining 230 kV line between DEC's Catawba Nuclear Station and Peacock Tie may become overloaded. Ancillary equipment upgrades may be performed in order to utilize the full conductor rating of the line.

For the loss of the parallel line, the remaining 230 kV line between DEC's McGuire Nuclear Station and Riverbend Steam Station may become overloaded. Presently, DEC mitigates loading issues on these lines by re-dispatching its generation at its Lincoln CT Station. Future corrective action may involve adding reactors on both lines in order to increase the impedance, resulting in reduced flow.

For loss of the Jacksonville terminal of the Havelock-Jacksonville 230 kV line, the Havelock – New Bern 115 kV line may become overloaded. For loss of the Greenville terminal of the Aurora – Greenville 230 kV line, the Brunswick Plant #2 – Whiteville 230 kV line may become overloaded. Construction of the Jacksonville – Sutton North 230 kV line will alleviate these loading issues. Based on engineering judgment, one static VAR compensator (SVC) is included in Scenario 2 to mitigate voltage swings associated with the variability of wind generation output as well as the potential area transmission network voltage instability associated with the opening and closing of transmission lines. The inclusion of a SVC provides a starting point for mitigating voltage instability, but a dynamic stability analysis, required for an actual generator interconnection, would be necessary to determine whether the SVC is sufficient for all system conditions.

The violations identified in the PJM system involved the Landstown 230 kV injection point. The Landstown – Stumpy Lake 230 kV line was overloaded for the loss of the Landstown – Fentress 230 kV line and the Landstown – Lynnhaven 230 kV line was overloaded for the loss of the Landstown – Stumpy Lake 230 kV line. The loss of either 230 kV line caused wind penetration flows from the Landstown injection point to be redirected over the local 230 kV network. A second Landstown – Stumpy Lake 230 kV line was added to mitigate the overload on the first line. The second overload was mitigated by upgrading the terminal equipment on the Landstown – Lynnhaven 230 kV line to increase its conductor ratings.

6.3 Scenario 3 Analysis Results

N-1 thermal violations were identified in the DEC, PEC and PJM systems for the Scenario 2 analysis, shown in the following Table 6:

Table 6 - Scenario 3 N-1 Thermal Violations

FROM	NAME	TO	NAME	KV	CKT	AREA	CONTINGENCY	RATE B	% FLOW
314504	Thalia 230 kV	314486	Lynnhaven 230 kV	230	1	PJM	6LANDSTN_6ST	788.00	154.15
314504	Thalia 230 kV	314474	Greenwich 230 kV	230	1	PJM	6LANDSTN_6ST	788.00	141.36
314508	Thrasher 230 kV 2	314466	Fentress 230 kV	230	1	PJM	LN 271	722.00	139.47
306334	Peacock Tie	306332	Catawba Nuclear Station	230	1	DEC	PEACOCKB	320.00	132.09
308334	Peacock Tie	306332	Catawba Nuclear Station	230	2	DEC	PEACOCKW	320.00	132.09
314316	Locks 230 kV	314285	Chaparral 230 kV	230	1	PJM	8CARSON _8MD	319.00	121.40
314511	Virginia Beach 115 kV	314438	Store Del Pt 115 kV	115	1	PJM	6LANDSTN_6ST	179.00	118.16
306543	Riverbend Steam Station	306540	McGuire Nuclear Station	230	1	DEC	NORMANB	557.00	115.40
308543	Riverbend Steam Station	306540	McGuire Nuclear Station	230	2	DEC	NORMANW	557.00	115.21
314287	Chesterfield 230 kV 2	314276	Basin 230 kV	230	1	PJM	8CARSON _8MD	470.00	113.08
314472	Green Run 230 kV	314486	Lynnhaven 230 kV	230	1	PJM	LN 2007	637.00	111.84
314278	Bermuda 230 kV	314286	Chesterfield 230 kV 1	230	1	PJM	8CHCKAHM _8S	470.00	106.30
314438	Store Del Pt 115 kV	314483	Long Creek 115 kV	115	1	PJM	6LANDSTN_6ST	179.00	104.97
314303	Hopewell 230 kV	314278	Bermuda 230 kV	230	1	PJM	8CHCKAHM _8S	478.00	104.57
314465	Elizabeth River NUG 230 kV	314514	Yadkin 230 kV	230	1	PJM	LN 231B	583.00	102.90
304358	Wadesboro Bowman School Tap 230	304248	Ansonville 230	230	1	CPLE	LILESVILLEW	398.00	102.41
304985	Lilesville 230	304358	Wadesboro Bowman School Tap 230	230	1	CPLE	LILESVILLEW	398.00	102.40
304985	Lilesville 230	306542	Oakboro Tie	230	1	CPLE	LILESVILLEB	398.00	101.93
304248	Ansonville 230	306542	Oakboro Tie	230	1	CPLE	LILESVILLEW	398.00	101.58
314474	Greenwich 230 kV	314472	Green Run 230 kV	230	1	PJM	LN 2007	637.00	100.74

CONTINGENCY DEFINITION:
6LANDSTN_6ST: Loss of Landstown - Stumpy 230 kV Ckt. 1
6LANDSTN_6ST: Loss of Landstown - Stumpy 230 kV Ckt. 1
LN 271: Loss of Landstown - Fentress 230 kV Ckt. 1
PEACOCKB: Loss of Catawba - Peackcock 230 kV Ckt. 2
PEACOCKW: Loss of Catawba - Peacock 230 kV Ckt. 1
8CARSON _8MD: Loss of Carson - Midlothian 500 kV Ckt. 1
6LANDSTN_6ST: Loss of Landstown - Stumpy 230 kV Ckt. 1
NORMANB: Loss of McGuire - Riverbend 230 kV Ckt. 2
NORMANW: Loss of McGuire - Riverbend 230 kV Ckt. 1
8CARSON _8MD: Loss of Carson - Midlothian 500 kV Ckt. 1
LN 2007: Loss of Lynnhaven - Thalia 230 kV Ckt. 1
8CHCKAHM _8S: Loss of Chickahominy - Surry 500 kV Ckt. 1
6LANDSTN_6ST: Loss of Landstown - Stumpy 230 kV Ckt. 1
8CHCKAHM _8S: Loss of Chickahominy - Surry 500 kV Ckt. 1
LN 231B: Loss of Thrasher - Huntsman Chemical 230 kV Ckt. 1
LILESVILLEW: Loss of Oakboro - Liles SS 230 kV Ckt. 1
LILESVILLEW: Loss of Oakboro - Liles SS 230 kV Ckt. 1
LILESVILLEB: Loss of Oakboro - Ansonville 230 kV Ckt. 1
LILESVILLEW: Loss of Oakboro - Liles SS 230 kV Ckt. 1
LN 2007: Loss of Lynnhaven - Thalia 230 kV Ckt. 1

The PJM system experienced the most severe N-1 thermal violations in Scenario 3. The violations occurred on the Dominion 230 kV system and extended beyond the area of the Landstown injection point. The PJM network was expected to be most stressed in Scenario 3 given the wind injection and the considerable transfer into the PJM system. Scenario 3 modeled 4,500 MW of wind penetration into Landstown and approximately 1,500 MW of transfer into the PJM system from the DEC and PEC systems.

Given the results and the size of the Landstown wind injection, it was determined that reinforcing the Dominion 500 kV network in the area would be the most effective in accommodating the flow of wind power and mitigating the identified issues. The following upgrades were implemented in the case to alleviate the issues within the PJM system: a second Surry – Chickahominy 500 kV line; a second Chickahominy 500/230 kV transformer; a reconfiguration of the Chickahominy 500 kV ring bus; Chaparal – Locks 230 kV terminal equipment upgrade to increase conductor ratings; and a Landstown – Fentress 500 kV line to replace the Landstown – Fentress 230 kV line added as a network reinforcement during Scenario 3 development.

For the loss of the parallel line, the remaining 230 kV line between DEC's Catawba Nuclear Station and Peacock Tie may become overloaded. Ancillary equipment upgrades may be performed in order to utilize the full conductor rating of the line.

For the loss of the parallel line, the remaining 230 kV line between DEC's McGuire Nuclear Station and Riverbend Steam Station may become overloaded. Presently, DEC mitigates loading issues on these lines by re-dispatching its generation at its Lincoln CT Station. Future corrective action may involve adding reactors on both lines in order to increase the impedance, resulting in reduced flow.

For the loss of the Lilesville – Rockingham 230 kV White line, the Ansonville – Lilesville 230 kV line and the Ansonville – Oakboro 230 kV line may become overloaded. For the loss of the Lilesville – Rockingham 230 kV Black line, the Lilesville – Oakboro 230 kV line may become overloaded. Re-dispatching the Anson Unit will alleviate these loading issues. The Anson Unit is generally considered to be a peaking unit. As this is a non-peaking case, re-dispatch of the unit alleviated these loading issues.

Based on engineering judgment, two static VAR compensators (SVCs) are included in Scenario 3 to mitigate voltage swings associated with the variability of wind generation output as well as the potential area transmission network voltage instability associated with the opening and closing of transmission lines. The inclusion of a SVC provides a starting point for mitigating voltage instability, but a dynamic stability analysis, required for an actual generator interconnection, would be necessary to determine whether the SVC is sufficient for all system conditions.

Section 7.0 Network Reinforcement Cost Estimate

The cost estimate information provided in this section were determined by each of the study participants based on planning experience and knowledge with previously proposed or constructed transmission projects in their respective regions. The cost estimate information is not based on a comprehensive engineering scope of the proposed transmission solutions, which would provide the most accurate cost estimate.

The table below reflects the cost estimates for Scenario 1:

Table 7 - Scenario 1 Cost Estimates of Upgrades

	Scenario #1 Element	Area	Miles	Transformers	Substation	Unit Cost $, millions	Element Cost $, millions
1	Morehead 500 kV Switching Station	PEC			1	30	30
2	Jacksonville 500 kV Sub	PEC		2		30	60
3	Jacksonville - Morehead Sw Sta 500 kV Lines	PEC	80			2.5	200
4	Wommack 500 kV Sub	PEC		2		30	60
5	Jacksonville - Wommack 500 kV Line	PEC	40			3	120
6	Southport 500 kV Switching Station	PEC			1	30	30
7	Sutton North 500 kV Sub (incldg 230 kV work)	PEC		2		35	70
8	Southport - Sutton North 500 kV Lines	PEC	60			2.5	150
9	Cumberland - Sutton North 500 kV Line	PEC	70			3	210
10	Cumberland 500 kV Sub - Add terminals	PEC			1	2	2
						Total PEC Cost $, millions	932

For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need.

The table below reflects the cost estimates for Scenario 2:

Table 8 - Scenario 2 Cost Estimates of Upgrades

	Scenario #2					Unit Cost	Element Cost
	Element	Area	Miles	Transformers	Substation	$, millions	$, millions
1	Reactors on McGuire - Riverbend 230 kV Lines	DEC					4
					Total DEC Cost $, millions		4
						Unit Cost	Element Cost
	Element	Area	Miles	Transformers	Substation	$, millions	$, millions
2	Morehead 500 kV Switching Station	PEC			1	30	30
3	Jacksonville 500 kV Sub	PEC		1		30	30
4	Jacksonville - Morehead Sw Sta 500 kV Lines	PEC	80			2.5	200
5	Wommack 500 kV Sub	PEC		1		30	30
6	Jacksonville - Wommack 500 kV Line	PEC	40			3	120
7	Cumberland - Jacksonville 500 kV Line	PEC	70			3	210
8	Jacksonville - Sutton North 230 kV Line	PEC	45			2	90
9	Southport 500 kV Switching Station	PEC			1	30	30
10	Sutton North 500 kV Sub (incldg 230 kV work)	PEC		2		35	70
11	Southport - Sutton North 500 kV Lines	PEC	60			2.5	150
12	Cumberland - Sutton North 500 kV Line	PEC	70			3	210
13	Cumberland 500 kV Sub - Add terminals	PEC			2	2	4
14	SVC at Sutton North	PEC			1	40	40
					Total PEC Cost $, millions		1,214
						Unit Cost	Element Cost
	Element	Area	Miles	Transformers	Substation	$, millions	$, millions
15	2nd Landstown - Stumpy Lake 230 kV Line	PJM	4			1	4
					Total PJM Cost $, millions		4

For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need. The Jacksonville – Sutton North 230 kV line was added to address loading issues observed during N-1 analysis.

The table below reflects the cost estimates for Scenario 2:

Table 9 - Scenario 3 Cost Estimates of Upgrades

	Scenario #3 Element	Area	Miles	Transformers	Substation	Unit Cost $, millions	Element Cost $, millions
1	Reactors on McGuire - Riverbend 230 kV Lines	DEC					4
					Total DEC Cost $, millions		4
	Element	Area	Miles	Transformers	Substation	Unit Cost $, millions	Element Cost $, millions
2	Morehead 500 kV Switching Station	PEC			1	30	30
3	Jacksonville 500 kV Sub	PEC		2		30	60
4	Jacksonville - Morehead Sw Sta 500 kV Lines	PEC	120			2.5	300
5	Wommack 500 kV Sub	PEC		2		30	60
6	Jacksonville - Wommack 500 kV Lines	PEC	80			2.5	200
7	Cumberland - Jacksonville 500 kV Line	PEC	70			3	210
8	Jacksonville - Sutton North 500 kV Line	PEC	45			3	135
9	Wake - Wommack 500 kV Line	PEC	65			3	195
10	Wake 500 kV Sub - Add terminals	PEC			1	2	2
11	Southport 500 kV Switching Station	PEC			1	30	30
12	Sutton North 500 kV Sub (incldg 230 kV work)	PEC		2		35	70
13	Southport - Sutton North 500 kV Lines	PEC	60			2.5	150
14	Cumberland - Sutton North 500 kV Line	PEC	70			3	210
15	Cumberland 500 kV Sub - Add terminals	PEC			2	2	4
16	SVC at Sutton North	PEC			1	40	40
17	SVC at Wommack	PEC			1	40	40
					Total PEC Cost $, millions		1,736
	Element	Area	Miles	Transformers	Substation	Unit Cost $, millions	Element Cost $, millions
18	Landstown 500 kV Substation	PJM			1	18.5	18.5
19	Landstown 500/230 kV Transformer	PJM		2		16	32
20	Chickahominy 500/230 kV Transformer	PJM		1		16	16
21	Surry - Chickahominy 500 kV Line	PJM	45			3.8	171
22	Landstown - Fentress 500 kV Line	PJM	15			3.8	57
23	Landstown - Yadkin 500 kV Line	PJM	10			3.8	38
24	2nd Landstown - Stumpy Lake 230 kV Line	PJM	4			1	4
25	2nd Stumpy Lake - Thrasher 230 kV Line	PJM	4			1	4
26	2nd Fentress - Thrasher 230 kV Line	PJM	8			1	8
					Total PJM Cost $, millions		349

For the PEC system, transmission upgrades from prior NCTPC wind studies were incorporated into the base cases in anticipation of the need.

Section 8.0 Summary of Conclusions

As a result of its proximity to the Virginia coast and the strength of the local transmission system, PJM's Landstown 230 kV substation is capable of handling wind injections up to 2,000 MW without major upgrades or system adjustments. Wind injections of greater than 4,500 MW in the Landstown area would require interconnection at the 500 kV level, along with upgrades to the 500 kV system and the local 230 kV system. The transmission system local to the injection points in PEC was not capable of handling the levels of injection in the study and required new transmission in order to transmit the power to stronger inland transmission buses for all levels of the study. Any issues identified in DEC were driven by the level of import rather than the magnitude of the wind injection and did not require major network upgrades; the levels of import in the study were up to 600 MW from PJM and up to 2,400 MW from PEC.

Integration of 3,000 – 10,000 MW of off-shore wind in North Carolina and Virginia would require approximately $1-2 billion in transmission upgrades. Details of the required upgrades and cost estimates are provided in Section 7.0. Detailed interconnection analysis of the studied systems would be required to reveal the full extent of necessary network improvements, but the analysis provided in this report is indicative of how the studied systems would respond to large amounts of wind penetration at off-peak load conditions.

APPENDIX A – 2027 SUMMER / ON-PEAK WIND (OFF-PEAK LOAD) CASE AREA INTERCHANGE

PJM INTERCONNECTION, DUKE ENERGY CAROLINAS, PROGRESS ENERGY CAROLINAS (EAST)

PJM Interconnection Net Interchange – MW

	Base	Scenario 1	Scenario 2	Scenario 3
PJM Interchange to non-CPLE/Duke Areas	1753	1753	1753	1753
CPLE (Offshore Wind)	0	400	0	-1500
CPLE (NCEMC #1)	100	100	100	100
CPLE (NCEMC #2)	100	100	100	100
CPLE (SEPA-Kerr)	95	95	95	95
Duke (Offshore Wind)	0	600	0	0
PJM Net Interchange MW Total	2048	3048	2048	548

Note: Positive net interchange indicates an export and negative interchange an import.

<u>Duke Energy Carolinas Net Interchange – MW</u>

	Base	**Scenario 1**	**Scenario 2**	**Scenario 3**
CPLE (NCEMC)	0	0	0	0
CPLE (NCEMC/Hamlet)	0	0	0	0
CPLE (Offshore Wind)	0	-1200	-1800	-2400
DVP (PJM)	-2	-2	-2	-2
DVP (Offshore Wind)	0	-600	0	0
SCEG (Chappells)	-2	-2	-2	-2
SCPSA (New Horizons/NHEC)	0	0	0	0
SCPSA (PMPA)	-28	-28	-28	-28
SEPA (Hartwell)	-155	-155	-155	-155
SEPA (Thurmond)	-113	-113	-113	-113
SOCO (City of Seneca)	-19	-19	-19	-19
SOCO (NCEMC)	-83	-83	-83	-83
CPLE (Broad River)	0	0	0	0
CPLE (NCEMC/Catawba)	205	205	205	205
CPLE (Rowan)	150	150	150	150
CPLW (Rowan)	0	0	0	0
DVP (NCEMC)	50	50	50	50
Duke Energy Net Interchange MW Total	3	-1797	-1797	-2397

Note: Positive net interchange indicates an export and negative interchange an import.

Progress Energy Carolinas (East) Net Interchange – MW

	Base	**Scenario 1**	**Scenario 2**	**Scenario 3**
AEP (NCEMC)	-100	-100	-100	-100
AEP (NCEMC#2)	-100	-100	-100	-100
CPLW (Transfer)	0	0	0	0
DUKE (Broad River)	0	0	0	0
DUKE (NCEMC/Catawba)	-205	-205	-205	-205
DUKE (Rowan)	-150	-150	-150	-150
DVP (SEPA-KERR)	-95	-95	-95	-95
DVP (Offshore Wind)	0	-400	0	1500
CPLW (Transfer)	0	0	0	0
DUKE (NCEMC)	0	0	0	0
DUKE (NCEMC/Hamlet)	0	0	0	0
DUKE (Offshore Wind)	0	1200	1800	2400
DVP (NCEMC)	0	0	0	0
Progress Energy Carolinas (East) Net Interchange MW Total	-650	150	1150	3250

Note: Positive net interchange indicates an export and negative interchange an import.