2019 Economic Study Offshore Wind Transmission Interconnection Analysis

Planning Advisory Committee

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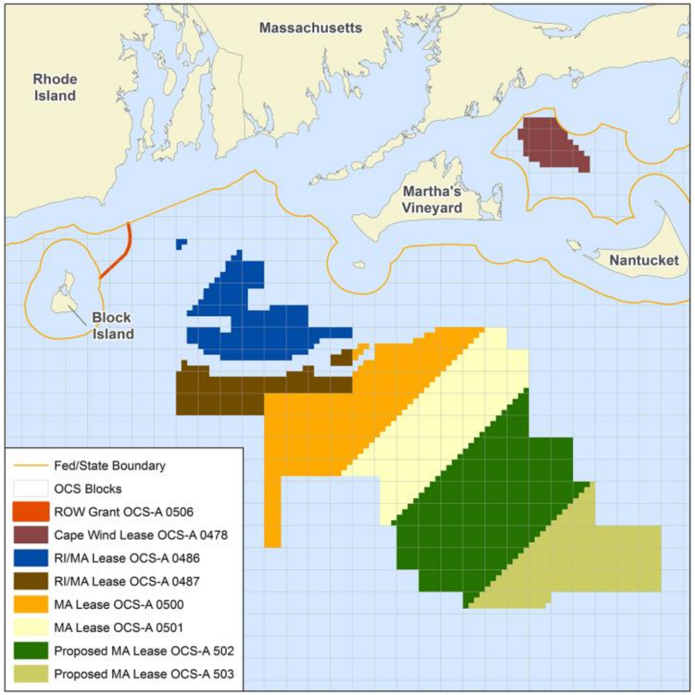
Background: Summary of the NESCOE 2019 Economic Study Request

- Scenario Analysis
  - Increasing levels of incremental offshore wind resources under anticipated 2030 New England system load conditions
  - Reference case: 0 MW
  - High case: up to 8,000 MW
- Production Impacts
  - Energy, Capacity, Ancillary Services
  - Prices and Air Emissions
  - Ancillary Services Requirements
- Transmission Interconnection Analysis
  - High-Level Conceptual Transmission Overlays
  - Transmission Upgrade Concepts
  - Various Points of Interconnection

Focus of this presentation

Scenarios Requested and Total MW Studied

	MW of New Offshore Wind[1]	Total MW Studied[2]
By 2030	1,000	2,000
	2,000	3,000
	4,000	5,000
By 2035	5,000	6,000
	7,000	8,000



- Primary location of new resources: MA or RI/MA Wind Energy Areas (WEA) on the outer Continental Shelf
- Remaining amount of new offshore wind resources would be from a yet-to-be determined WEA in the Gulf of Maine

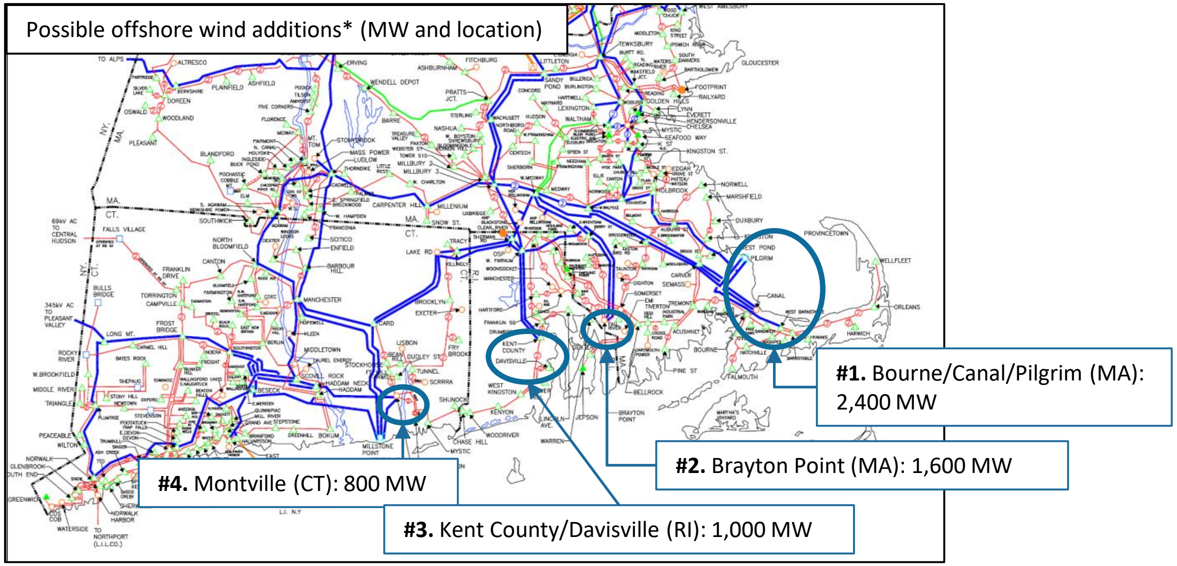
[1] Scenarios identified in NESCOE's request; Presentation to Planning Advisory Committee, April 25, 2019.
[2] Includes 1,000 MW of wind already contracted at the time of NESCOE's request.

ISO Interconnection Transmission Study

- For the NESCOE 2019 Economic Study Request, the ISO developed future interconnection scenarios for offshore wind
- The ISO focused on the interconnection points identified by offshore wind interconnection customers with interconnection requests in the ISO queue
- Based on the knowledge gained through the completion of several of the interconnection studies for those requests, the ISO identified the approximate MW quantities that could interconnect without major transmission upgrades beyond these local points
- The ISO then sought to identify the upgrades that would be needed to continue to increase the interconnection levels beyond those initial amounts

Study Finding: Anticipated Injection Capabilities Without Major Transmission Reinforcements

- Interconnection customers are proposing to use AC cable connections from the wind farm lease areas to coastal 345 kV substations
- Based on the currently expected transmission system for 2030, the ISO anticipates that the depicted levels (5,800 MW) of offshore wind additions have the potential to be accomplished without major additional 345 kV reinforcements*

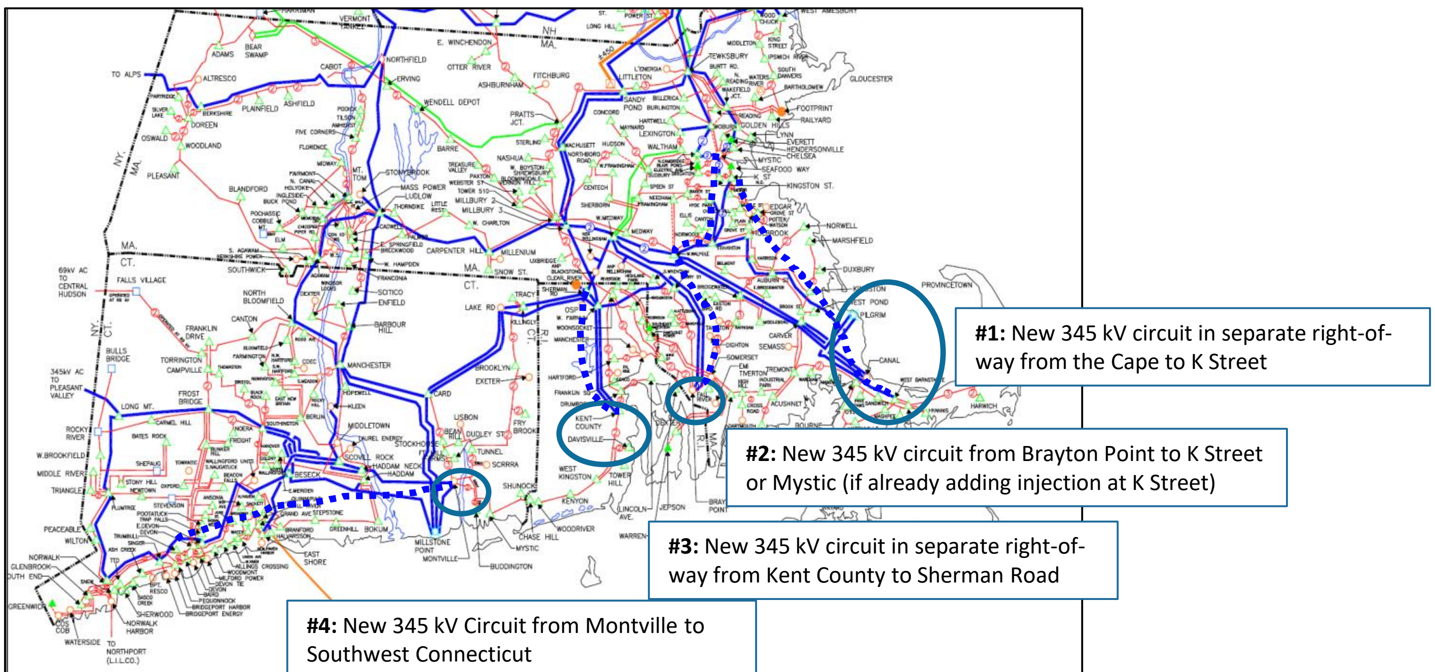


***Some 345 kV reinforcement/expansion may still be needed for this scenario**. This anticipation is preliminary (system impact studies have not been completed for all of these MW). This anticipates minimal interconnection at nameplate levels and capacity interconnection at intermittent capacity values – does not anticipate all of the MW being able to run simultaneously at nameplate levels at all times on the system.

Note that the numbering (#) of the interconnection points has changed from earlier PAC presentations

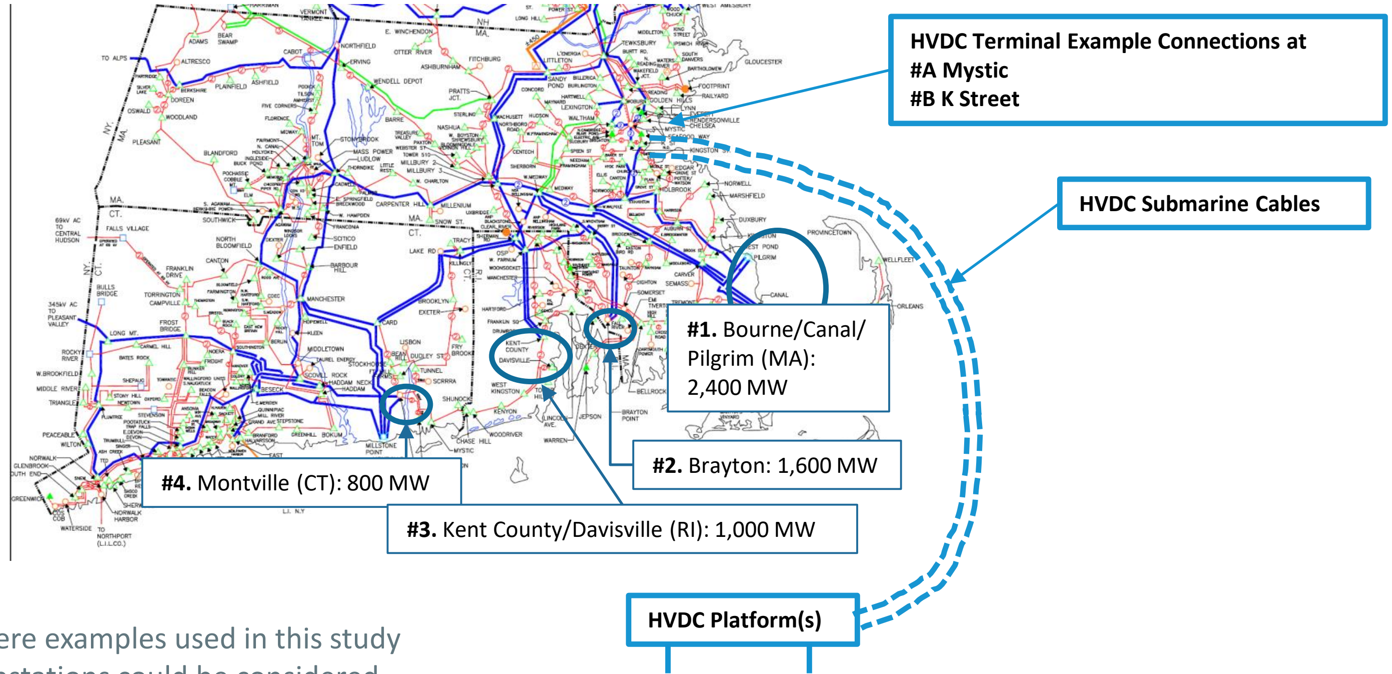
Study Finding: Additional Southern Shore Injections Likely Require Significant Reinforcements

- Additional offshore wind injections at the interconnection points on the southern shore, above the levels shown on the prior slide, would require significant transmission reinforcements, as represented conceptually below



Study Finding: HVDC Alternatives Can Avoid Major Onshore Transmission Additions

- Alternatively, additional offshore wind could be connected while avoiding significant onshore transmission upgrades by using High Voltage Direct Current (HVDC) connections from the offshore wind farms to load center substations*



*Mystic & K Street were examples used in this study
Other load center substations could be considered
This assumes FCA 13 retirements have occurred, including the retirement of Mystic 8 & 9

Study Finding: Infrastructure Summary

MW Injection Levels by Interconnection Point(s) and Associated Transmission Infrastructure Summary

Total Offshore Wind Injection (MW)_Scenario	Offshore Wind Connected to Shore at these Points Using AC Cables				Connected at these Points Using HVDC Cables		Offshore Infrastructure		Onshore Infrastructure
	#1 Bourne/ Barnstable	#2 Brayton Point	#3 Kent Co/ Davisville	#4 Montville	#A Mystic	#B K Street	Offshore AC Cables[3]	Offshore HVDC Cables[4]	Major Onshore Additional Transmission Identified to Accommodate Interconnection Scenario[1]
2,000	800	500	700	-	-	-	5	-	None
3,000	1,500	800	700	-	-	-	8	-	None
5,000	2,400	800	1,000	800	-	-	13	-	None
5,800	2,400	1,600	1,000	800	-	-	15	-	None
7,000	2,400	1,600	1,000	800	1,200	-	15	1	None
8,000_1	2,400	1,600	1,000	800	1,200	1,000	15	2	None
8,000_2	3,400	1,600	1,000	800	1,200	-	17	1	New approximately 60 mile 345 kV line in separate right-of-way from Barnstable, MA to K Street Substation
8,000_3	2,400	2,600	1,000	800	1,200	-	17	1	New approximately 50 mile 345 kV line in separate right-of-way from Brayton Point to K Street Substation (or Mystic if injection is already added at K Street)
8,000_4	2,400	1,600	2,000	800	1,200	-	17	1	New approximately 30 mile 345 kV line[2] in separate right-of-way from Kent Co, RI to Sherman Road Substation
8,000_5	2,400	1,600	1,000	1,800	1,200	-	17	1	New approximately 60 mile 345 kV line from Montville CT to Southwest CT

1. Note that some local 345 kV reinforcement/expansion is still likely to be needed for all interconnection scenarios
2. Note that significant congestion would be observed with this offshore wind injection and upgrade when the existing area combined cycle facilities are running
3. Each offshore three phase AC cable is assumed to be approximately 40-60 miles in length and is rated for approximately 400 MW, operating at 230-280 kV
4. Each offshore HVDC cable is assumed to be approximately 150-200 miles in length and is rated for up-to 1,200 MW

Injection Level Color Code

- (green) Injection level is below the level where major infrastructure beyond the local interconnection area would be needed
- (yellow) Injection level is at the limit above which major infrastructure beyond the local interconnection area would be needed for additional injections
- (red) Injection level is above the level where major infrastructure beyond the local interconnection area would be needed

Key Conclusions

- As summarized in the chart on the previous slide, approximately 5,800 MW of offshore wind can be interconnected using AC cable connections to interconnection points along the southern New England Coast without significant upgrades to the on-shore transmission network
  - Note that some local 345 kV reinforcement/expansion is still likely to be needed for this scenario
- Additional interconnections to these points would drive the need for significant network upgrades
- Alternatively, HVDC connections could be used to continue to travel further distances and connect additional offshore wind directly to the load centers
  - Connection of a total of 2,200 MW using offshore HVDC was identified without major on-shore transmission upgrades
  - In addition to the 5,800 MW connected using AC cables to the Southern New England Coast – this gives a total of 8,000 MW of connected offshore wind

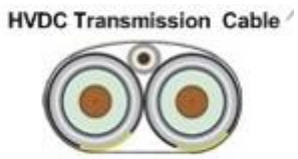
A DISCUSSION OF AC VERSUS HVDC CONNECTION OF OFFSHORE WIND

Submarine AC Cable

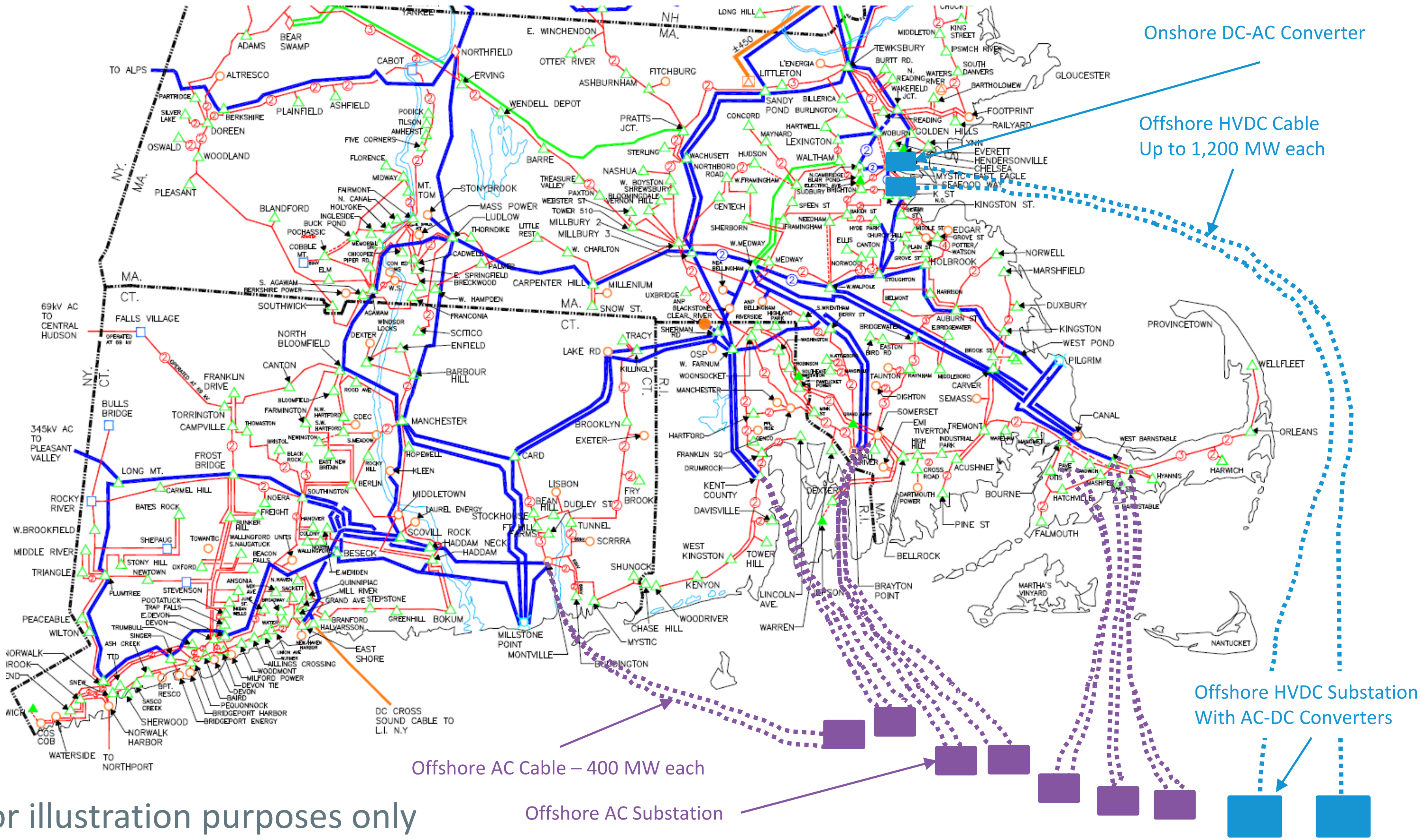
- Submarine AC cable can be used to connect from an offshore collector substation to the interconnection point at the onshore substation
- Submarine AC technology can be used for distances of up to approximately 40-60 miles
- Typical applications are operated at 225-275 kV and are rated to carry approximately 400 MW for each (three phase) cable
- Very commonly, developers have proposed projects to use two AC cables for an 800 MW project

Submarine DC Cable

- Submarine DC cable can also be used to connect from an offshore collector substation to the interconnection point at the onshore substation
- Submarine DC technology can be used for very long distances (hundreds of miles)
- Converter stations are needed at both ends (one at the offshore collector substation and one at the onshore interconnection point) to convert from DC back to AC
  - Converter stations add significantly to the overall cost
- A single HVDC cable can be used to connect up-to 1,200 MW of generation



Conceptual Application of Offshore Cable Technology: 8,000 MW Case (Scenario 8,000_1)



For illustration purposes only

TRANSMISSION INTERCONNECTION REVIEW

Summary of Results

Background of the Transmission Interconnection Review

- The transmission assessment for the 2019 NESCOE Economic Study was not a detailed interconnection study
  - The study did not seek to identify all of the solutions that would be needed to address the identified problems
- At the March 18, 2020 PAC meeting, the ISO presented a summary of the results of the analysis of the identified injection levels
- At the April 23, 2020 PAC meeting, the ISO presented additional results
  - These results are summarized here along with some additional information

Transmission Interconnection Analysis: Cape Cod Area

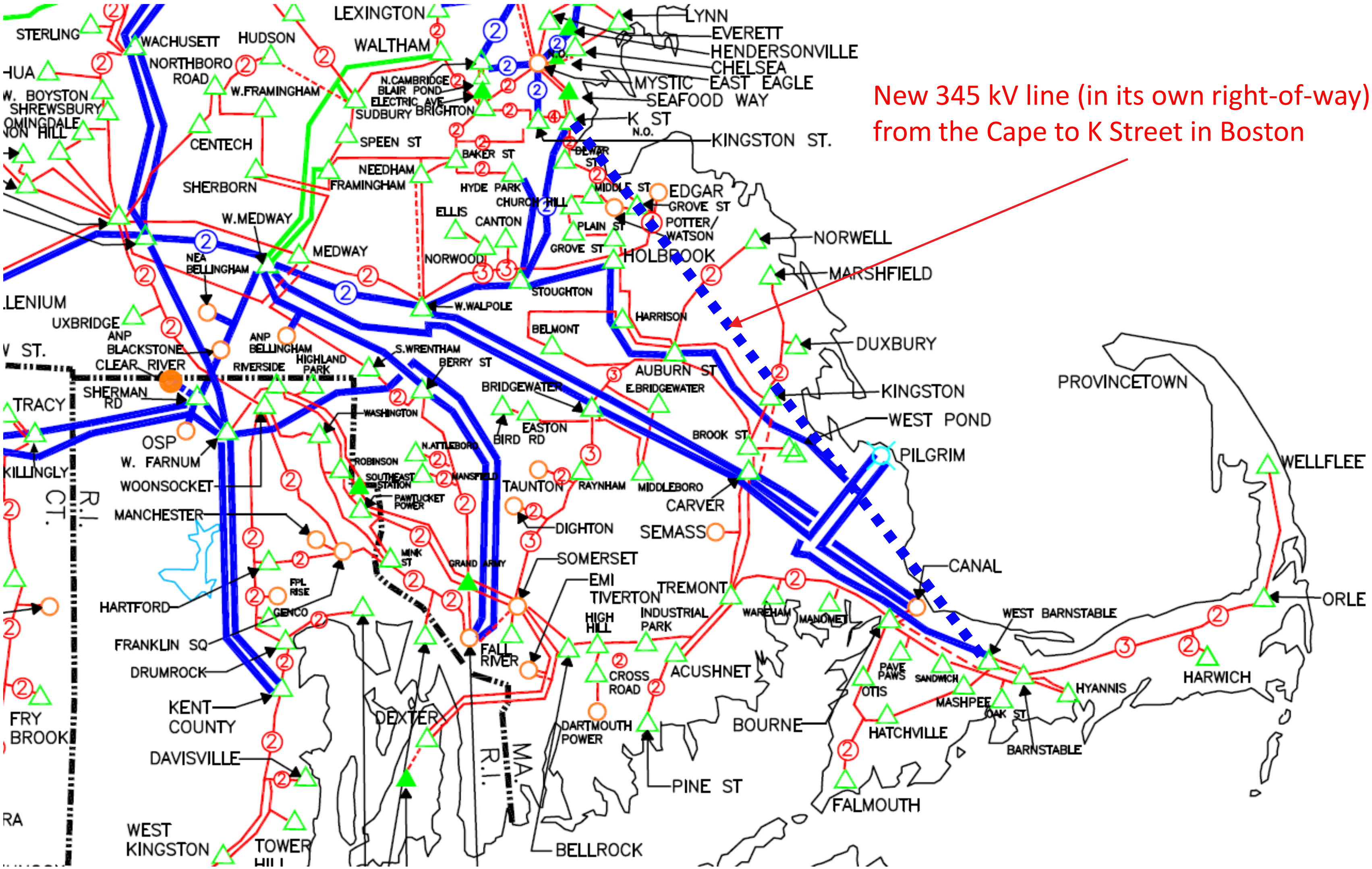
- Screening analysis of the addition of 3,200 MW (i.e. 800 MW* more than the 2,400 MW indicated in the base scenario) to the Cape Cod area identified the following limitations with the existing transmission system:
  - Thermal limitations, particularly the Stoughton – K Street 345 kV cables
  - Introduced significant exposure to problematic loss of right-of-way extreme contingencies
  - Very low short circuit ratios (relatively low system strength) indicating weak grid conditions expected to manifest as unstable behavior of the wind farms
  - Stability issues such as un-damped oscillations and degraded NPCC bulk power system behavior

*800 MW was studied for illustrative purposes.
Similar findings would be expected for 1,000 MW of additional injection.

What Were the Insights Gained from the Cape Cod Injection Analysis?

- The nature of the limitations found in the 3,200 MW case indicate that 2,400 MW of injection appears to represent a "hard ceiling" of the amount that can readily be interconnected to the Cape Cod area
  - Not only would new transmission be needed to address both the weak-grid issues and the thermal issues on the Stoughton-K Street 345 kV lines, but
  - The new transmission would have to be in its own right-of-way to avoid an unacceptable exposure to loss-of-supply (loss of up-to 3,200 MW of connected offshore wind) for the loss of the right-of-way

Significant New Transmission Would Be Needed to Resolve All of the Issues



Transmission Interconnection Analysis: Brayton Point Area

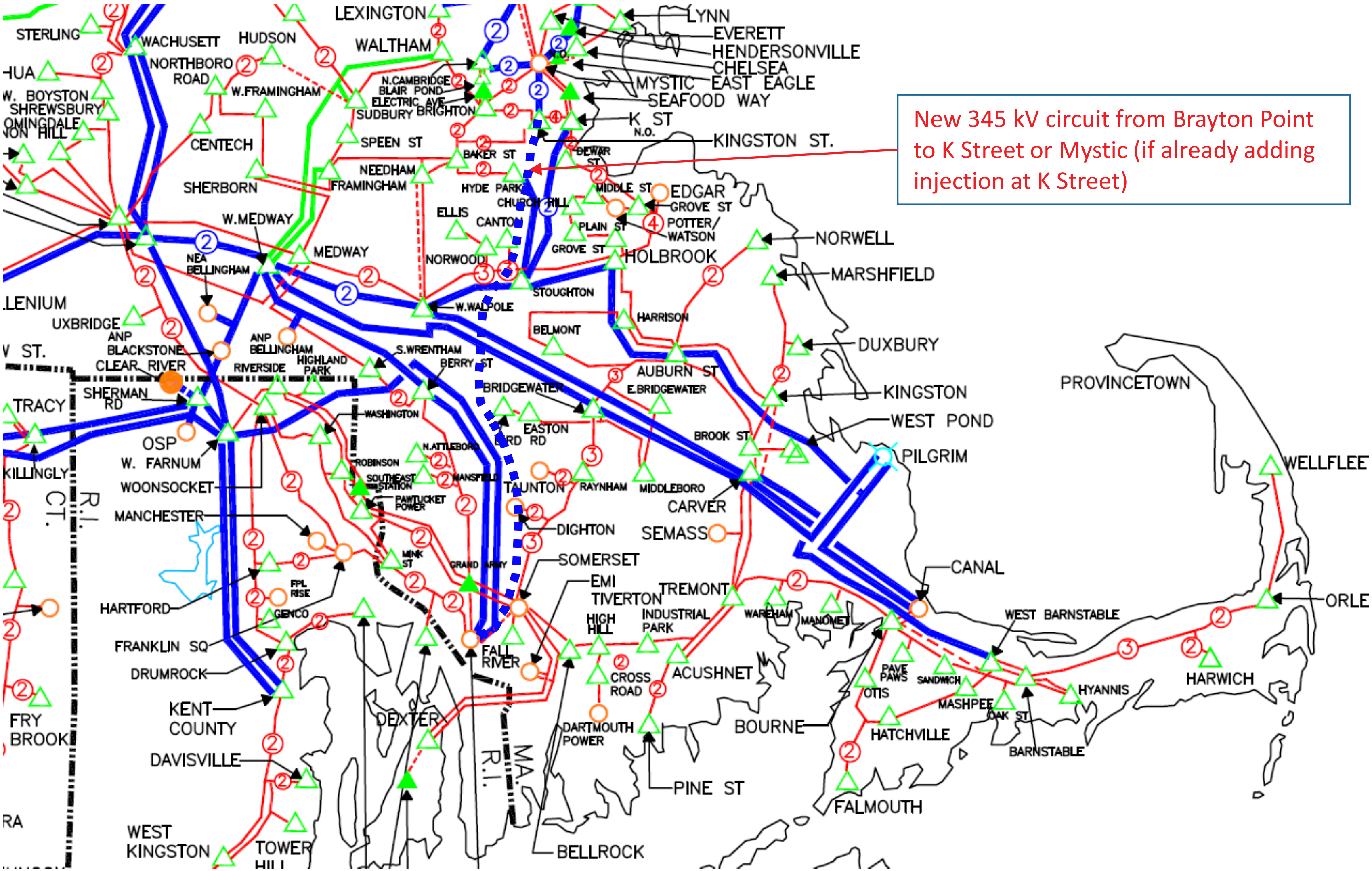
- Screening analysis of the addition of 2,400 MW (i.e. 800 MW* more than the 1,600 MW indicated in the base scenario) to the Brayton Point area identified the following limitations with the existing transmission system:
  - Numerous N-1 & N-1-1 thermal violations occur in the areas surrounding Brayton Point and Grand Army substations
  - Introduce significant exposure to problematic loss of right-of-way extreme contingencies
  - Very low short circuit ratios (relatively low system strength) indicating weak grid conditions expected to manifest as unstable behavior of the wind farms

*800 MW was studied for illustrative purposes.
Similar findings would be expected for 1,000 MW of additional injection.

What Were the Insights Gained from the Analysis of Brayton Point Upgrades?

- The nature of the limitations found in the 2,400 MW case indicated several problems that proved very difficult to effectively address with new transmission upgrades
  - Introduced or exacerbated thermal overloads
  - Greater density of existing circuits – more difficult to find separate rights-of-way

Identified Brayton Point Solution to Avoid Introduction of Additional Issues



New 345 kV circuit from Brayton Point to K Street or Mystic (if already adding injection at K Street)

Transmission Interconnection Analysis: Kent County Area

- Screening analysis of the addition of 1,800 MW (i.e. 800 MW* more than the 1,000 MW indicated in the base scenario) to the Kent County area identified the following limitations with the existing transmission system:
  - Numerous N-1 & N-1-1 thermal violations occur in the areas surrounding the Kent County substation
  - Introduced significant exposure to problematic loss of right-of-way extreme contingencies
  - Very low short circuit ratios (relatively low system strength) indicating weak grid conditions expected to manifest as unstable behavior of the wind farms

*800 MW was studied for illustrative purposes.
Similar findings would be expected for 1,000 MW of additional injection.

Transmission Interconnection Analysis: Montville Area

- Screening analysis of the addition of 1,600 MW (i.e. 800 MW* more than the 800 MW indicated in the base scenario) to the Kent County area identified the following limitations with the existing transmission system:
  - Numerous N-1 & N-1-1 thermal violations occur in the areas surrounding the Montville substation
  - Very low short circuit ratios (relatively low system strength) indicating weak grid conditions expected to manifest as unstable behavior of the wind farms

*800 MW was studied for illustrative purposes.
Similar findings would be expected for 1,000 MW of additional injection.

Evaluated the Addition of a New 345 kV line Between Kent County and Montville

- System performance was poor with the new line
- Many overloads on existing facilities after adding more offshore wind at Montville

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- System performance was poor with the new line
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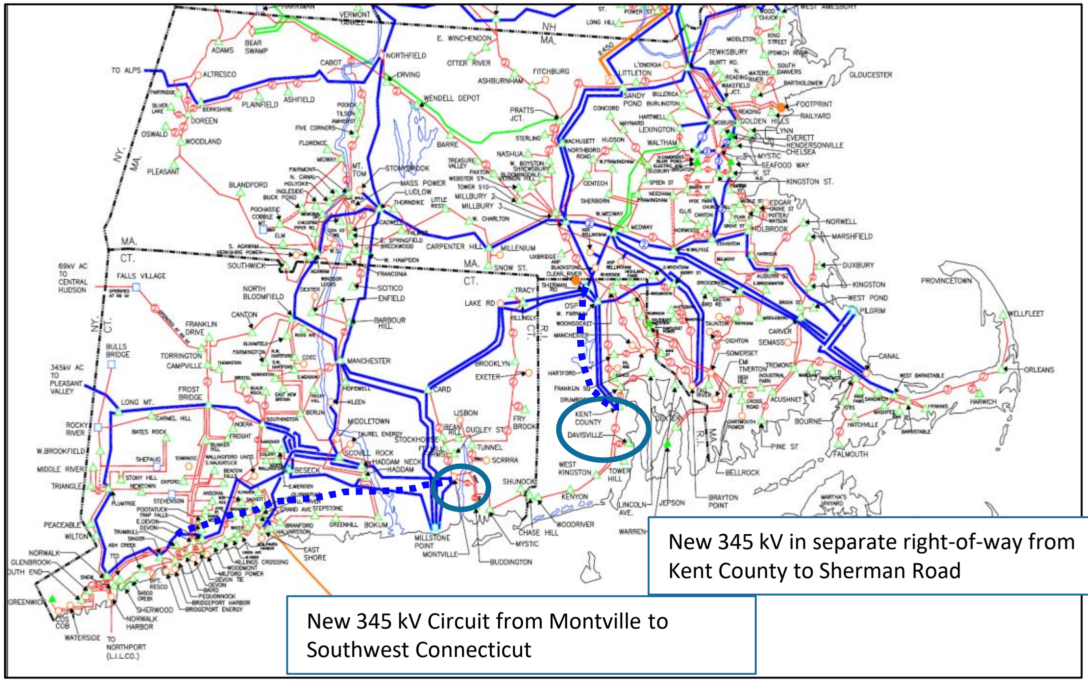
Alternative 345 kV Upgrades Identified Instead of Connecting Kent County to Montville

- New 345 kV circuit in separate right-of-way from Kent County to Sherman Road
  - Note that significant congestion would be observed with this offshore wind injection and upgrade when the existing area combined-cycle facilities are running
- New 345 kV Circuit from Montville to Southwest Connecticut



Summary

- Approximately 5,800 MW of offshore wind can be interconnected using AC cable connections to interconnection points along the southern New England coast without significant upgrades to the on-shore transmission network
  - Note that some local 345 kV reinforcement/expansion is still likely to be needed for this scenario
- Additional interconnections to these points would drive the need for significant network upgrades
- Alternatively, HVDC connections could be used to continue to travel further distances and connect additional offshore wind directly to the load centers
  - Connection of a total of 2,200 MW using HVDC was identified without major on-shore transmission upgrade
  - In addition to the 5,800 MW connected using AC cables to the southern New England coast – this gives a total of 8,000 MW of connected offshore wind

Next Steps

- Incorporation of the transmission results into the overall 2019 Economic Study Report

Questions