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2050 Transmission Study

Solution Development Update

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Purpose & Outline of Today's Presentation

- Today's presentation is a progress update on transmission solution development for the 2050 Transmission Study
- All results presented today are preliminary and subject to change as the study progresses
- Today's presentation will cover the following topics:
  - 2050 Transmission Study Overview
  - Key Lessons Learned to Date
  - Solution Development Progress
  - Summary & Next Steps

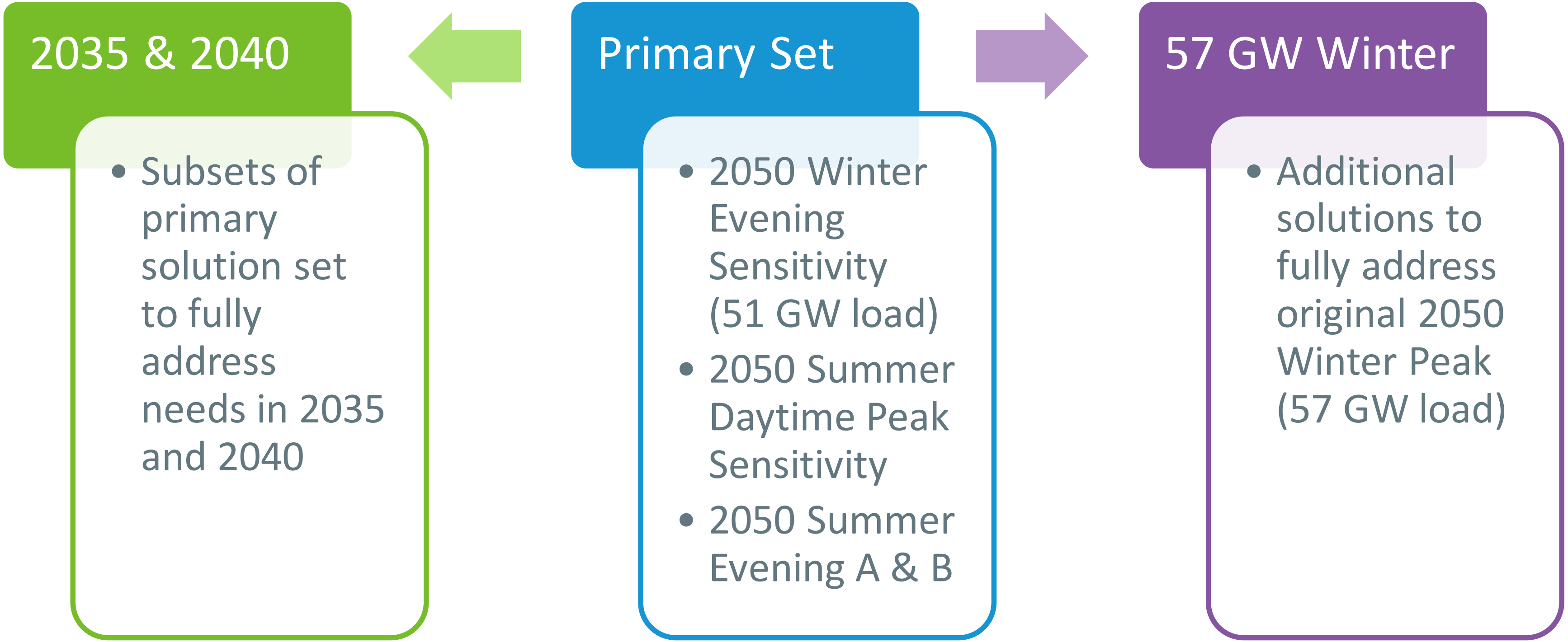
2050 TRANSMISSION STUDY OVERVIEW

2050 Transmission Study Overview

- In accordance with a recommendation from NESCOE's October 2020 "*New England States' Vision for a Clean, Affordable, and Reliable 21st Century Regional Electric Grid*," ISO-NE is conducting the 2050 Transmission Study in order to determine:
    - Transmission needs in order to serve load while satisfying NERC, NPCC, and ISO-NE reliability criteria in 2035, 2040, and 2050
    - Transmission upgrade "roadmaps" to satisfy those needs considering both constructability and cost
- ISO-NE has coordinated with NESCOE throughout this study
    - In November 2021, ISO-NE introduced the 2050 Transmission Planning Study Scope of Work , preliminary assumptions, and methodology
    - ISO-NE presented results showing transmission reliability concerns in peak load snapshots in March 2022, April 2022, and July 2022
- Today's presentation is an update on transmission solution development

Presented
April 28, 2022
PAC Meeting

2050 Study Solution Development Process



2035 & 2040

- Subsets of primary solution set to fully address needs in 2035 and 2040

Primary Set

- 2050 Winter Evening Sensitivity (51 GW load)
- 2050 Summer Daytime Peak Sensitivity
- 2050 Summer Evening A & B

57 GW Winter

- Additional solutions to fully address original 2050 Winter Peak (57 GW load)

2050 Study Solution Development: Current Status

2035 & 2040

- Subsets of primary solution set to fully address needs in 2035 and 2040

Primary Set

- 2050 Winter Evening Sensitivity (51 GW load)
- 2050 Summer Daytime Peak Sensitivity
- 2050 Summer Evening A & B

57 GW Winter

- Additional solutions to fully address original 2050

Currently, solution development is underway for the primary solution set. Details on the exact work performed so far will follow later in this presentation.

KEY LESSONS LEARNED TO DATE

Key Lessons Learned To Date

- While solution development is still in progress, the process has already revealed a number of key lessons
- These lessons may help illuminate:
  - General approaches to developing the transmission system needed for 2035, 2040, and 2050
  - Strategic decisions that the region will face while interconnecting new renewable energy sources
  - Questions to be answered prior to undertaking more detailed studies

Key Lessons Learned To Date

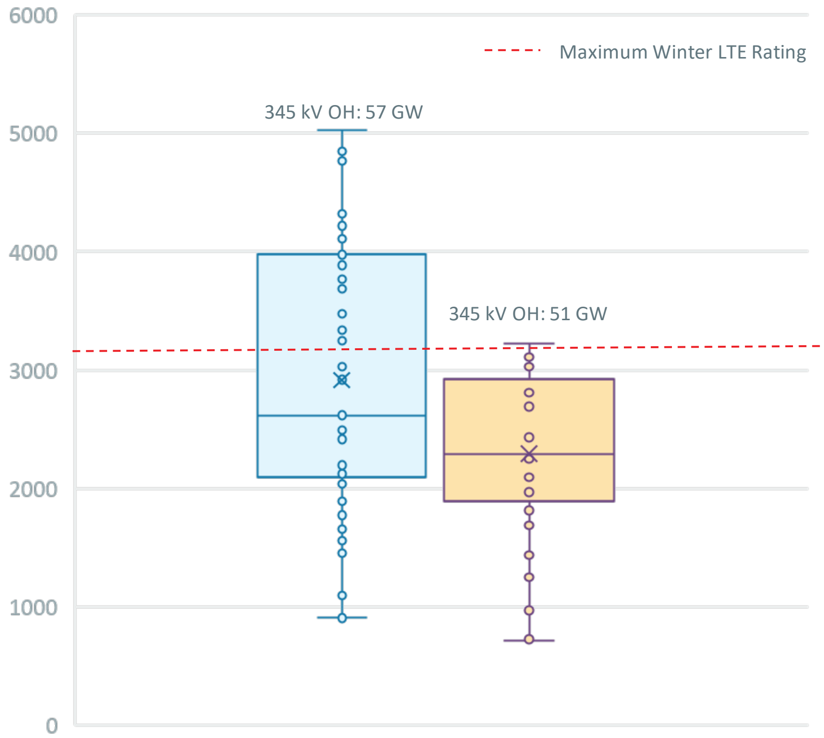
The following slides will discuss each of these lessons in further detail:

- Increasing Capacity of Existing Lines Is Effective
- 345/115 kV Transformers Are Critical
- Generator Sizes and Locations Can Affect Overloads
- Solutions Are Sensitive To Load Distribution

Increasing Capacity of Existing Lines Is Effective

- In many locations in New England, fully utilizing existing overhead transmission rights-of-way is enough to address many load-serving concerns in 2035, 2040, and 2050
- Solutions may include:
  - Reconductoring existing lines to increase current-carrying capacity
  - Replacing single conductors with double-bundled conductors
  - Rebuilding existing lines to accommodate the weight of larger conductors
  - Upgrading lines to higher operating voltage (e.g. 230 kV to 345 kV)

Increasing Capacity of Existing Lines Is Effective: Example



- Each dot on the graph represents the loading on an overloaded 345 kV line in the 51 GW and 57 GW 2050 Winter Peak snapshots
- The red line represents the typical maximum winter LTE rating of a 345 kV line
- Many overloads can be resolved by upgrading 345 kV lines to the largest standard conductor, rather than building brand-new lines
- Similar trend is true for 115 kV lines

345/115 kV Transformers Are Critical

- New England's future transmission system will need to transfer power from remote renewable sources to dense population centers on 345 kV lines, and then step power down to 115 kV to serve individual substations
- In the 51 GW 2050 Winter Peak snapshot, 62 of New England's 345/115 kV transformers are overloaded
- These transformers are expensive, and have a long lead time between the time an order is placed and delivery

Addressing 345/115 kV Transformer Overloads

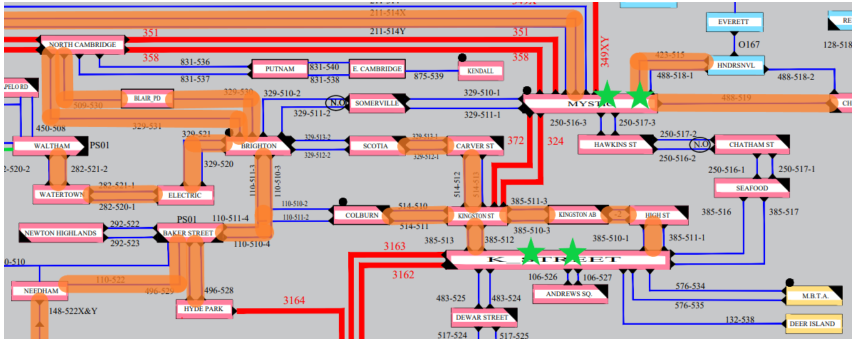
- In some cases, a single new 345/115 kV transformer can mitigate overloads on multiple existing transformers
- At other substations, overloads are severe enough that two new transformers are required
- When new renewable sources interconnect in or near load centers, interconnecting at 115 kV rather than 345 kV can reduce the need for additional 345/115 kV capacity

Generator Sizes and Locations Can Affect Overloads

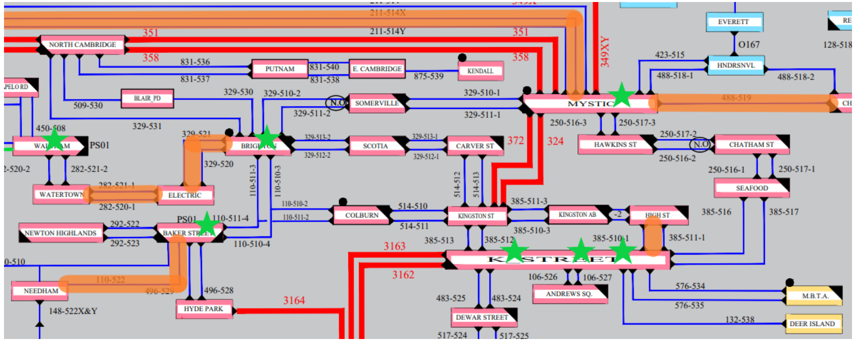
- Strategically locating points of interconnection (POIs) for new generating resources can reduce transmission overloads
- Previous 2050 Transmission Study presentations discussed locating generation in southern New England to reduce North-South stresses
- Further analysis has shown that location on a finer scale is also critical to limiting overloads
  - Choice of individual substations in urban areas
  - Choice of voltage level within a substation (115 vs. 345 kV)

Impacts of Generator Size and Location

Original approach: multiple large offshore wind interconnections at Mystic and K Street 345 kV



Potential optimized approach: smaller individual offshore wind interconnections at various 115 kV stations in and around Boston (including relocations from outside Boston)



In both figures, orange highlights show overloaded lines in the 51 GW 2050 Winter Peak snapshot. **Green** stars show the location of offshore wind interconnections.

Generator Size: Inherent Trade-Offs

- Large offshore wind interconnections, especially in Boston, can lead to overloads leaving the point of interconnection
- Smaller offshore wind interconnections can avoid this problem, but a trade-off exists:

Smaller wind interconnections

- Lower transmission upgrade costs
- Higher number of offshore connections
- Higher number of HVDC converters
- Higher generator lead costs

Larger wind interconnections

- Higher transmission upgrade costs
- Lower number of offshore connections
- Lower number of HVDC converters
- Lower generator lead costs

Generator Size: Proposal for Further Analysis

- To ensure efficient solution development in the Boston area, ISO-NE proposes to continue optimizing wind farm POI locations
- The trade-off between wind farm size and transmission upgrades will be addressed by choosing a standard wind farm size of 1200 MW for POIs in the Greater Boston area
  - 1200 MW is a common size in European offshore wind interconnections
  - Minimizes the number of HVDC converter stations and offshore connections without exceeding the 1200 MW source loss limit or requiring extensive transmission upgrades at the POIs
- Substations with multiple offshore wind interconnections (totaling greater than 1200 MW) will remain outside of Greater Boston, where fewer overloads are encountered in moving large amounts of wind out of POIs

Solutions Are Sensitive to Load Distribution

- Distribution of load among the substations in New England plays a critical role in transmission line/transformer loading
- Maximum load loss criteria of 300 MW for an N-1-1 contingency pair further sensitizes results to load distribution
- Load distribution is unlikely to drastically change the New England-wide total cost of upgrades, but influences the exact solutions chosen for longer-term transmission studies

Load Distribution: Examples

- A 115 kV load-serving substation in the Boston area is fed by two 115 kV lines, and has 308 MW of load
  - To avoid a 300 MW N-1-1 load loss, at least one new transmission line is required
  - A 10 MW reduction in load would eliminate this requirement
  - Other stations in the Boston area have just under 300 MW, and could drive new transmission lines if load is slightly increased
- A 115 kV overhead transmission line in central Vermont is loaded to 101.3% of its LTE rating
  - A small (~5 MW) shift in load from one end of the line to the other could be enough to drop the line's flow below 100% of LTE, eliminating an upgrade from the final solutions set

Load Distribution: Future Data Requirements

- In the 2050 Transmission Study, ISO-NE assumed that electrification leads to equal rates of load growth at each substation in a state
- Unequal load growth rates and changes in load distribution over time may eliminate some concerns identified in this study, or lead to other concerns not identified here
- In future longer-term transmission studies, ISO-NE may request substation-specific load growth information from transmission/distribution companies

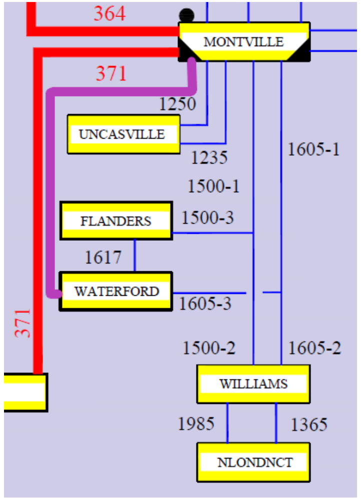
SOLUTION DEVELOPMENT PROGRESS

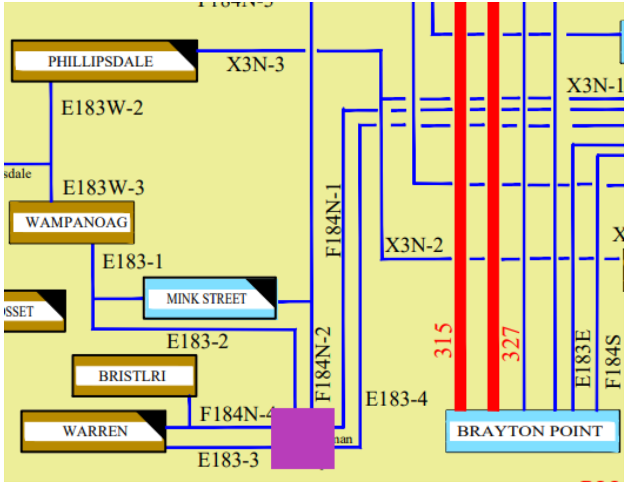
Solution Development Approach

- Most solution development so far has focused on urban areas
  - Highest density of load
  - More underground transmission, which cannot be upgraded in-place as easily as overhead transmission
  - The 2050 Transmission Study will suggest solutions for any location in New England where overloads are observed, whether in an urban area or not
- Focus is initially on the 51 GW 2050 Winter Peak snapshot
  - Winter peak snapshot shows the greatest extent of overloads, and solutions for winter peak will likely address summer peak overloads
  - Offshore wind POI relocation is occasionally spot-checked in summer peak snapshots, where wind output is assumed to be lower, to ensure that solutions remain effective during summer peak conditions

Solutions to Address 300 MW N-1-1 Load Loss

- A number of solutions are proposed to address N-1-1 contingency pairs that result in the loss of >300 MW of load
- For example:
  - Third line into an area served by two lines (center)
  - Switching station to break up line with multiple tapped load-serving stations (at right)





Overhead Line Rebuilds

- As described in the April 2022 PAC presentation, ISO-NE will use per-mile cost assumptions for line rebuild/reconductoring
- Cost assumptions have been developed through an analysis of past asset condition rebuilds
- Assumed costs shown at right

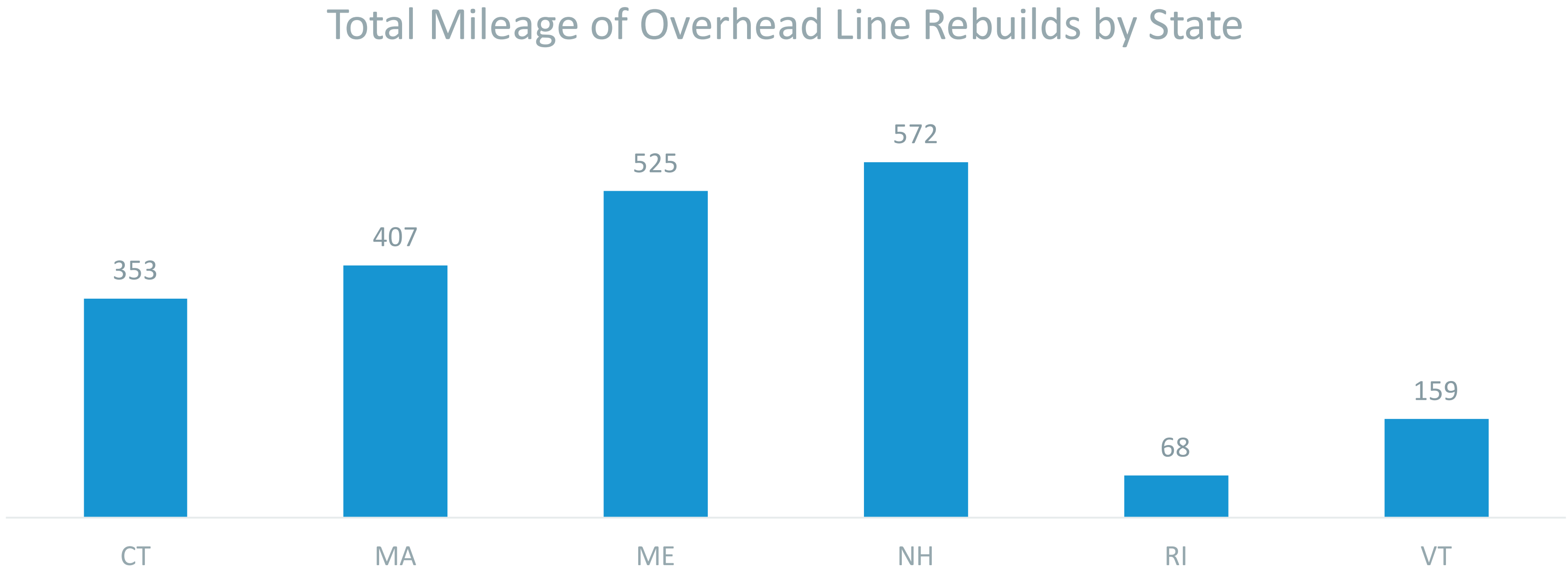
Voltage	Assumed Cost
69 kV	$2M/mile
115 kV	$2M/mile
230 kV	$3M/mile
345 kV	$5M/mile

Overhead Line Rebuilds

- Preliminary total mileage of existing lines to be rebuilt for higher capacity, and assumed cost, shown here
  - Breakdown of mileage by state shown on the next slide
- Some lines may need to be rebuilt for asset condition by 2050, so estimated costs may partially overlap with asset condition projects

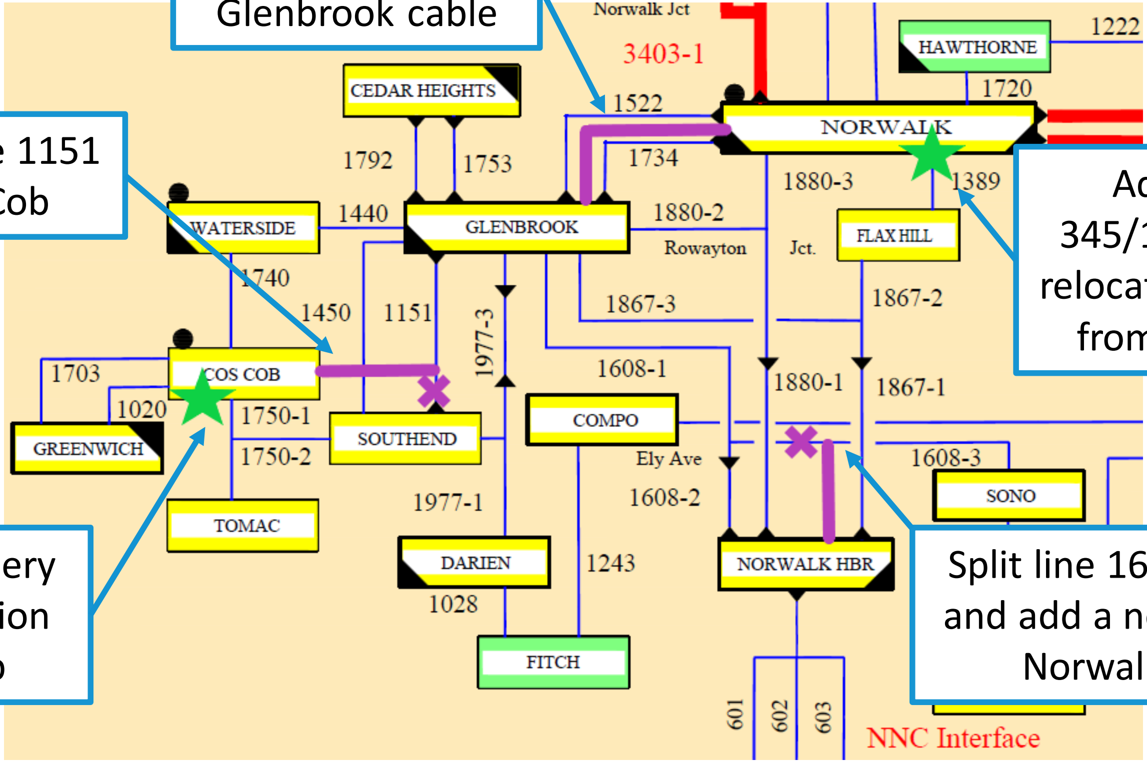
Voltage	Miles of Rebuilt Lines	Assumed Cost
69 kV	111	$0.22 billion
115 kV	1,491	$2.98 billion
230 kV	63	$0.19 billion
345 kV	419	$2.09 billion
Total	**2,084**	**$5.48 billion**

Overhead Line Rebuilds: Mileage by State



Numbers indicate preliminary total mileage of existing lines to be rebuilt for higher capacity. Results subject to change as study progresses.

Southwest Connecticut: Preliminary Solutions



Third Norwalk-Glenbrook cable

Extend line 1151 to Cos Cob

Add third Norwalk 345/115 kV transformer, relocate offshore wind POI from 345 kV to 115 kV

Relocate battery interconnection to Cos Cob

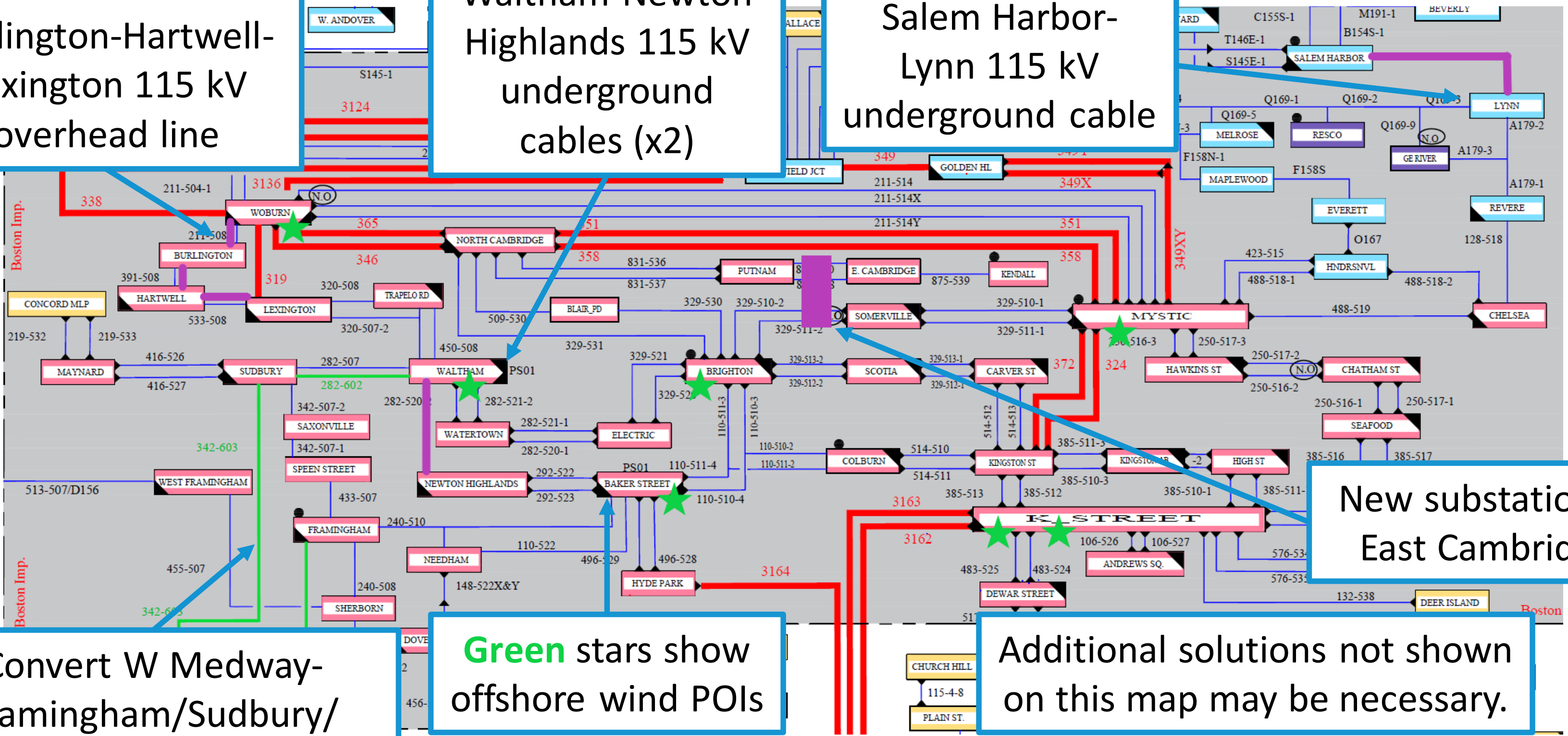
Split line 1608 at Ely Ave and add a new cable into Norwalk Harbor

Boston Area: Solution Development Progress

- Strategic relocation of offshore wind POIs has reduced the extent of overloads in Boston
  - Preliminary list of POIs shown at right

Substation	OSW Size
K Street 345 kV	1200 MW
Mystic 115 kV	1200 MW
K Street 115 kV	1200 MW
Woburn 115 kV	1200 MW
Brighton 115 kV	1200 MW
Waltham 115 kV	1200 MW
Baker Street 115 kV	1200 MW

Boston Area: Preliminary Solutions



Second Woburn-Burlington-Hartwell-Lexington 115 kV overhead line

Waltham-Newton Highlands 115 kV underground cables (x2)

Salem Harbor-Lynn 115 kV underground cable

New substation in East Cambridge

Convert W Medway-Framingham/Sudbury/ Waltham 230 kV to 345 kV

Green stars show offshore wind POIs

Additional solutions not shown on this map may be necessary.

SUMMARY AND NEXT STEPS

Summary and Key Take-Aways

Increasing Capacity of Existing Lines Is Effective

345/115 kV Transformers Are Critical

Generator Sizes and Locations Can Affect Overloads

Solutions Are Sensitive To Load Distribution

Solution development is still in progress, so exact transmission solutions shown today should be regarded as preliminary and subject to change.

Next Steps

- Feedback on this 2050 Transmission Study presentation may be submitted to pacmatters@iso-ne.com by January 3, 2023
- Solution development work will be ongoing throughout 2023
- Consultant has begun to develop cost estimates for more complex/challenging solution components
- Next update to PAC anticipated in late Q1/early Q2 2023

Questions