2050 Transmission Study

Preliminary N-1 and N-1-1 Thermal Results

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Overview

- Background
- Review of Assumptions
- Thermal Results by Snapshot
- Thermal Results – Some Additional Perspective
- Key Takeaways
- Next Steps

BACKGROUND

Background

- In October 2020, the New England States Committee on Electricity (NESCOE) released the "*New England States' Vision for a Clean, Affordable, and Reliable 21st Century Regional Electric Grid*"
  - One of the recommendations in the vision statement was for ISO-NE to conduct a comprehensive long-term regional transmission planning study to inform all stakeholders of the amount and type of transmission infrastructure needed to cost-effectively integrate clean energy resources and DERs across the region to meet New England states' energy policy requirements and goals
- The ISO has coordinated with NESCOE to fulfill this recommendation
  - In November 2021, ISO-NE introduced the 2050 Transmission Planning Study Scope of Work, preliminary assumptions, and methodology
- Today, the ISO will provide a summary review of the assumptions discussed at the November 2021 PAC and review the preliminary N-1 and N-1-1 results

Objectives

- Given the future load and resource scenarios described in the "New England States' Vision for a Clean, Affordable, and Reliable 21st Century Electric Grid" determine the following for 2035, 2040 and 2050
  - Transmission needs in order to serve load while satisfying NERC, NPCC, and ISO-NE reliability criteria
  - Transmission upgrade "roadmaps" to satisfy those needs considering both constructability and cost
- The future load and resource assumptions will be based on the "All Options" pathway in the "*Energy Pathways to Deep Decarbonization*" report, which is also the basis for Scenario 3 in NEPOOL's 2021 Economic Study – Future Grid Reliability Study (FGRS) Phase I
  - This data shall be referred to as the "All Options Pathway" data in this presentation

Objectives Beyond the Scope of the 2050 Transmission Study

- Identifying all the infrastructure required for interconnecting clean energy resources and DER
  - Interconnection facilities
  - Distribution facilities
- Classification (and cost allocation) of any needs as:
  - Network upgrades which would be identified in an Interconnection Study
  - A reliability need which would be identified in a Needs Assessment Study/RFP
- An operational assessment encompassing the hours around the snapshots
- Economic analysis using production cost modeling
- Resource Adequacy analysis using probabilistic modeling techniques

Snapshots

- The 2050 Transmission Study SOW presentation introduced the concept of snapshots
  - A snapshot is a combination of load and resources from the All Options Pathway data for contingency analysis
  - The snapshots capture the highest load periods
- The hourly load data for 2035, 2040, and 2050 from the All Options Pathway load data was reviewed and peak load hours were determined
- Two Summer Evening Peak cases were evaluated to capture the New England-wide evening peak (peak A) and the northern New England non-coincidental evening peak (peak B)
- A total of 12 cases (four cases each for 2035, 2040, and 2050) were evaluated

Snapshot	Months	Hours
Summer Daytime Peak	May – September	9 AM to 5 PM
Summer Evening Peak A	May – September	7 PM to 10 PM
Summer Evening Peak B	May – September	7 PM to 10 PM
Winter Evening Peak	January – April	4 PM to 10 PM

Note: October-December were not included in snapshots because the conditions in these months did not lead to the most stressed conditions

Methodology

- The analysis was restricted to thermal steady-state analysis
  - DC contingency analysis has been used to identify thermal constraints and will be used to develop transmission upgrades
    - This analysis is intended to identify transmission needs that would require major transmission line additions
  - Voltage and transient stability analysis may be considered as part of future assessments
    - Requires additional data and assumptions
    - Violations are typically solved with substation upgrades that require minimal siting

REVIEW OF ASSUMPTIONS

Power Consumption in the Snapshots

- The 2050 Transmission Study utilized the All Options Pathway load data
  - The 12 categories in the All Options Pathway load data were reduced to two categories in the 2050 Transmission Study: Non-EV load and EV load
  - The loads are also shown below in aggregated categories for informational purposes

All Options Pathway Categories	Aggregated Categories	Loads Modeled in Snapshots
Commercial other	Other Load	Non-EV Load
Industry		
Residential other		
Commercial air conditioning	Air Conditioning	
Residential air conditioning		
Commercial space heating	Heating Electrification	
Residential space heating		
Commercial water hearing		
Residential water heating		
Light duty vehicles	Transportation Electrification	EV Load
Other transport		
EV Time-of-Use		

Power Consumption by Snapshot

- The power consumption levels represent a significant increase to the load levels used in a typical Needs Assessment
  - 2031 90/10 CELT* Summer Peak Load – EE = 27,520 MW
  - 2031 90/10 CELT* Winter Peak Load – EE = 21,938 MW

Power Consumption** by Snapshot (MW)				
Year	Summer Daytime Peak	Summer Evening Peak A (New England Coincident Peak)	Summer Evening Peak B (Northern New England Peak)	Winter Evening Peak
2035	29,375	26,749	25,741	35,116
2040	32,447	32,968	31,968	43,046
2050	40,004	38,601	38,492	56,997

* Based on the 2021 CELT Report

** Power Consumption is assumed to include distribution losses, and reductions due to EE, but not include station service, mill loads, reserve requirements, or transmission losses

Resource Representation by Snapshot

- The All Options Pathway resource data provides nameplate MW values for the study years
  - All oil, coal, diesel, and municipal solid waste (MSW) resources assumed retired by 2035

- Availability of the Resource varied by snapshot

	Nameplate Capacity (MW)			Availability		
Generation Type	2035	2040	2050	Summer Daytime Peak	Summer Evening Peak	Winter Peak
Nuclear	3,526	3,526	3,526	100%	100%	100%
Biomass	772	772	772	100%	100%	100%
Natural Gas (CCGT & CT)	15,848	16,548	16,645	100%	100%	100%
Hydro (RoR and Pondage)	1,814	1,814	1,814	Historical	Historical	Historical
Hydro Pumped Storage	1,841	1,841	1,841	Offline	Discharging	Discharging
Battery Energy Storage Systems (BESS)	2,729	3,237	7,040	Offline	Discharging	Discharging
PV (Rooftop and Ground Mount)	23,714	31,475	56,665	40%	10%/0%*	0%
Onshore Wind	3,006	3,006	3,006	5%	5%	65%
Offshore Wind	9,449	16,633	31,954	5%	5%	40%
Totals	62,699	78,852	123,263			

* Some Evening Peak snapshots occurred before sunset while some occurred after sunset

Note 1: Several changes were made from the All Options Pathway data, these were presented in the November Scope of Work

Note 2: The 2050 Transmission Study assumes no forced outages

THERMAL RESULTS BY SNAPSHOT

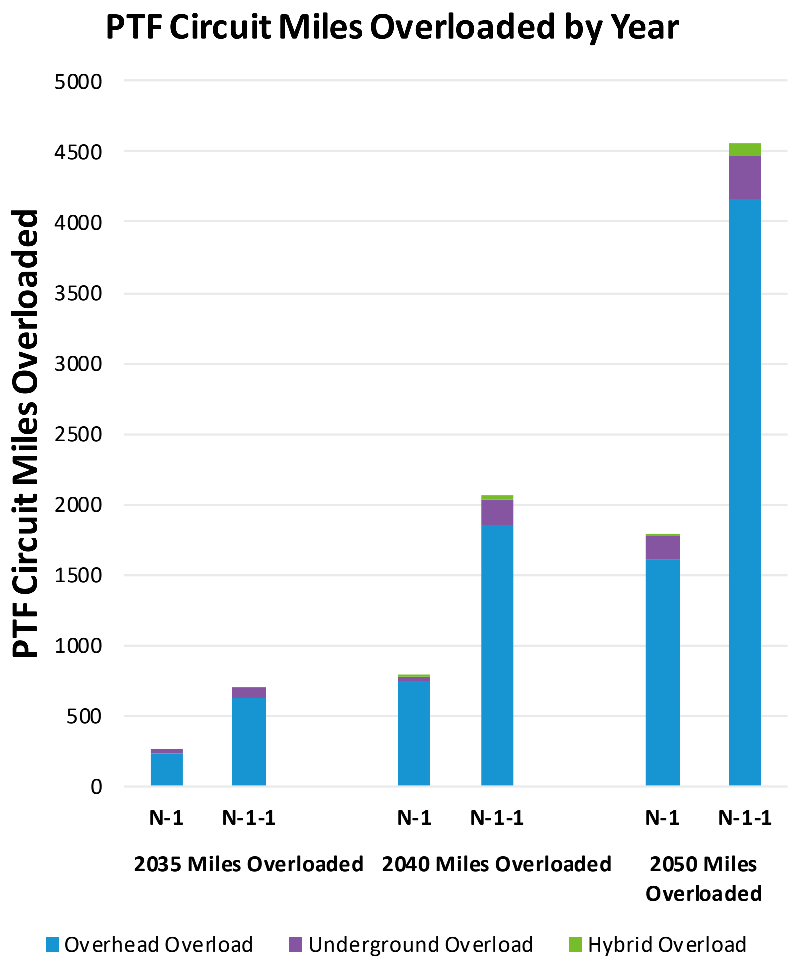
Key Metrics

Capturing and Summarizing the Results for PAC

- A typical Needs Assessment presentation identifies criteria violations individually. However, the number of violations identified in the 2050 Transmission Study make this impractical
  - Full results with the exact list of criteria violations have been provided in spreadsheet form on the PAC website
- Today's results are presented using two key metrics
  - Circuit miles of overloaded Pool Transmission Facilities (PTF) lines (includes overhead lines and underground cables)
  - Count of overloaded PTF elements
    - PTF line segments (includes overhead lines and underground cables)
    - PTF transformers
- As a reference point, New England has approximately
  - 9,000 circuit miles of PTF lines (includes overhead lines and underground cables)
  - 1,550 PTF line segments (includes overhead lines and underground cables)
  - 150 PTF transformers

N-1 and N-1-1 Results Snapshot Summary

PTF line overloads in any of the snapshots



- Each bar on this slide represents the total miles of PTF line overloads found between the four snapshots for the respective year
- Most of the PTF line overloads occur in 2050 and for overhead lines

Note: Hybrid overloads represent lines that have both overhead and underground sections

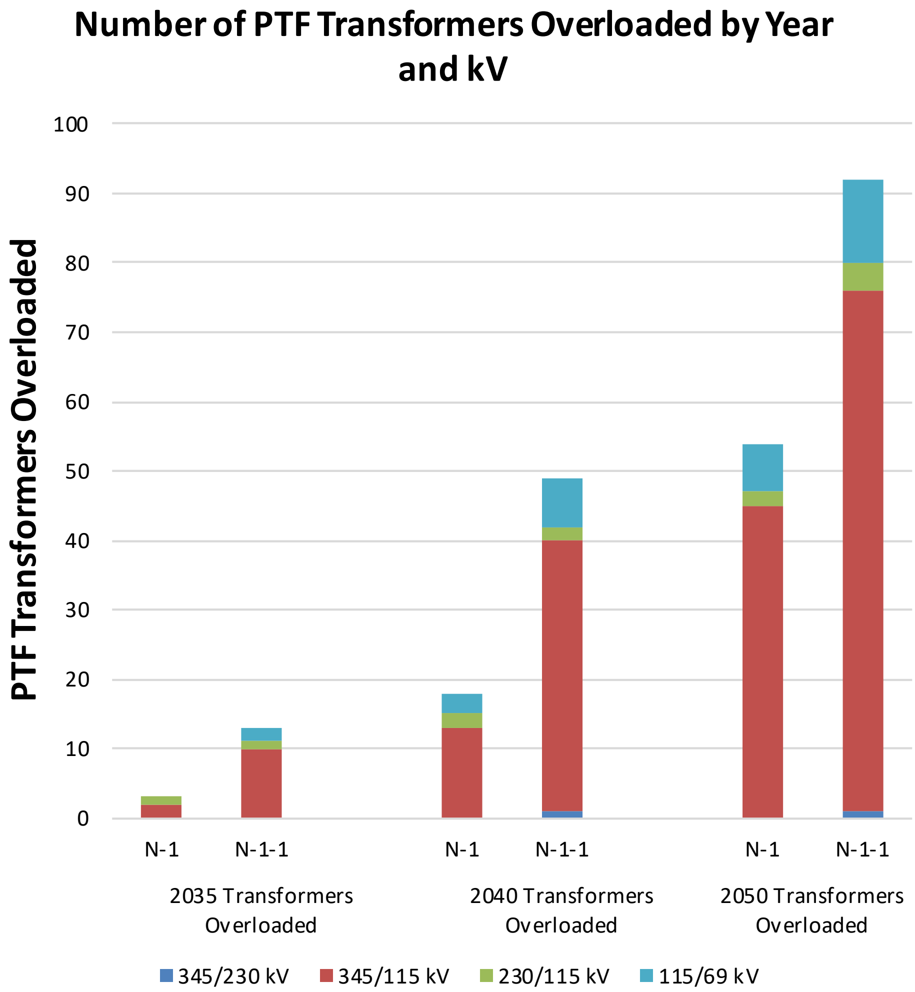
N-1 and N-1-1 Results Snapshot Summary, cont.

PTF Facility overloads in any of the snapshots

	Number of Overloaded PTF Facilities		
	2035	2040	2050
N-1 Line Segments	32	83	284
N-1-1 Line Segments	104	289	681
N-1 Transformers	3	19	55
N-1-1 Transformers	13	50	93

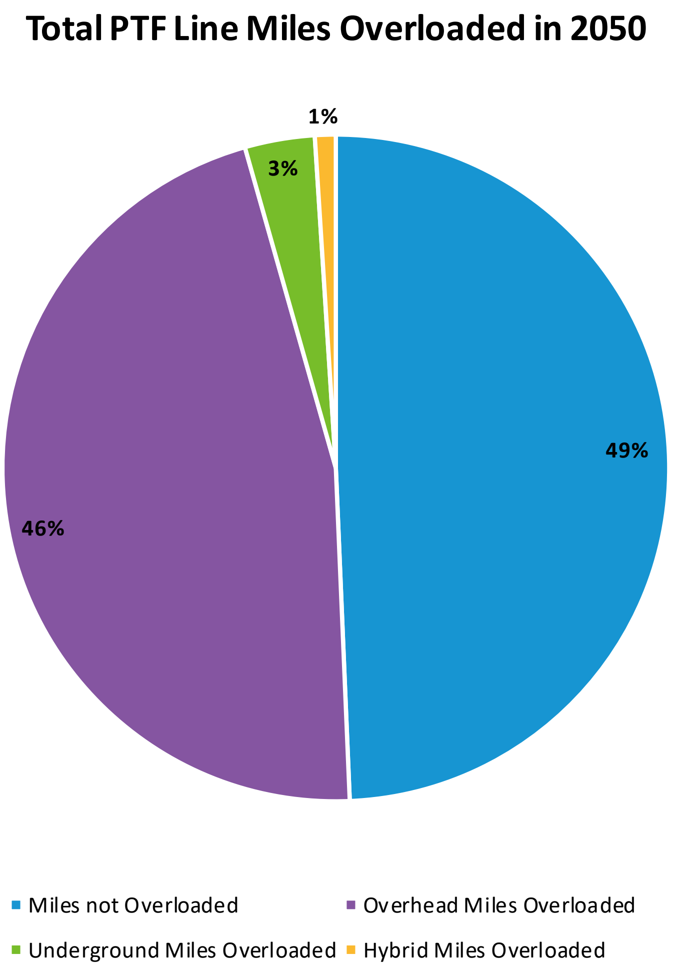
N-1 and N-1-1 Results Snapshot Summary, cont.

PTF transformer overloads in any of the snapshots



- Most overloads occur on 345/115 kV transformers
- N-1-1 column includes all N-1 overloads plus all N-1-1 overloads
  - For both transformers and transmission lines, only N-1-1 results will be shown moving forward
  - N-1 results are generally a subset of N-1-1 results

Percentage of Total Lines Overloaded in 2050



- Approximately half of the total PTF line miles in New England are overloaded in 2050
- This is ~4,500 miles out of ~9,000 miles
- The next slides depict those overloads by snapshot

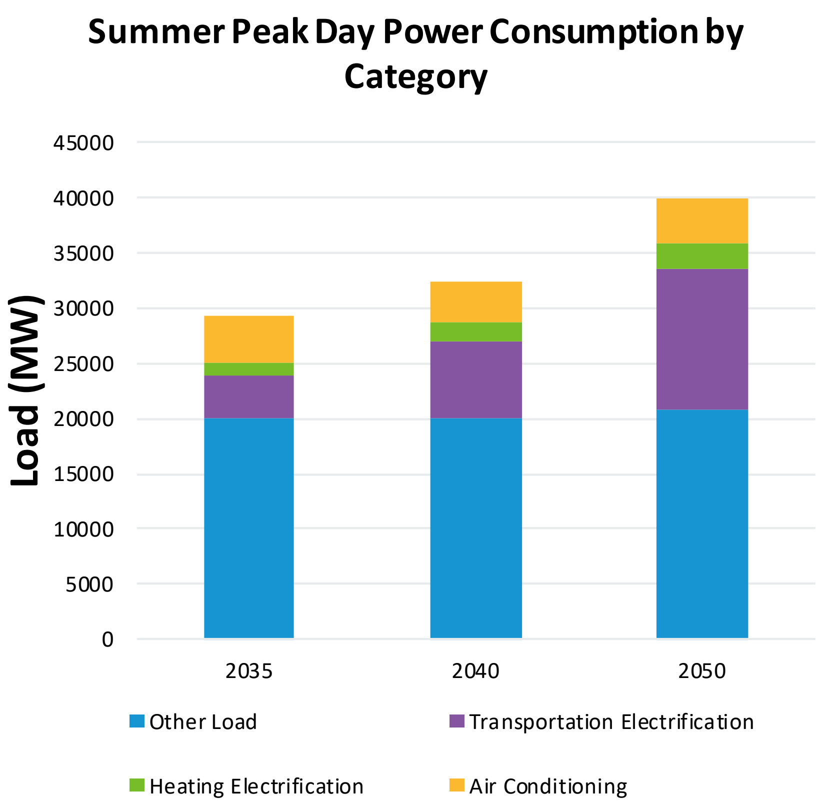
SUMMER DAYTIME PEAK SNAPSHOT

9 AM to 5 PM

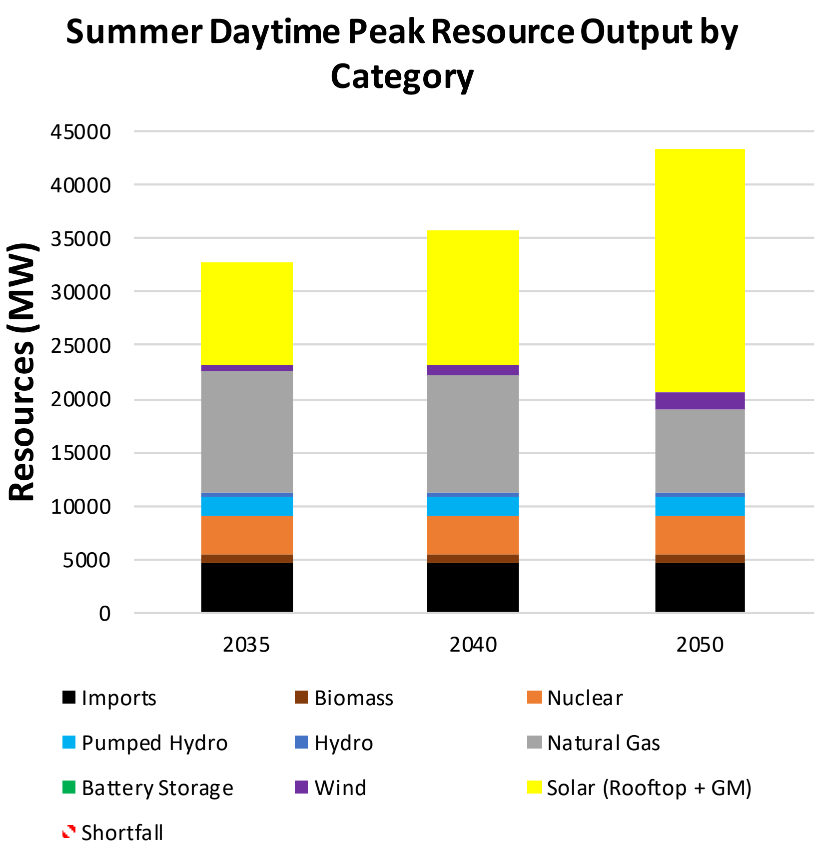
Summer Daytime Peak Snapshot

Application of the Load and Resource Assumptions

Load



Resources



Note: Difference between load and generation is due to station service, mill loads and transmission losses

Summer Daytime Peak Snapshot Transfers

Interface	FCA 16 Transfer Capability (MW)*	2035 Snapshot (MW)	2040 Snapshot (MW)	2050 Snapshot (MW)
ME - NH	1,900	2,156	1,706	1,621
North - South	2,725	5,076	5,563	6,393
East - West	3,500	-864	-719	-976
West - East	3,000	888	756	911
SEMARI Export	3,400	-593	-703	118
Boston Import	5,250	4,487	4,717	6,278
CT Import	3,400	-493	246	862
SWCT Import	2,800	1,821	2,620	3,492
NY-NE	1,400**	0	0	0

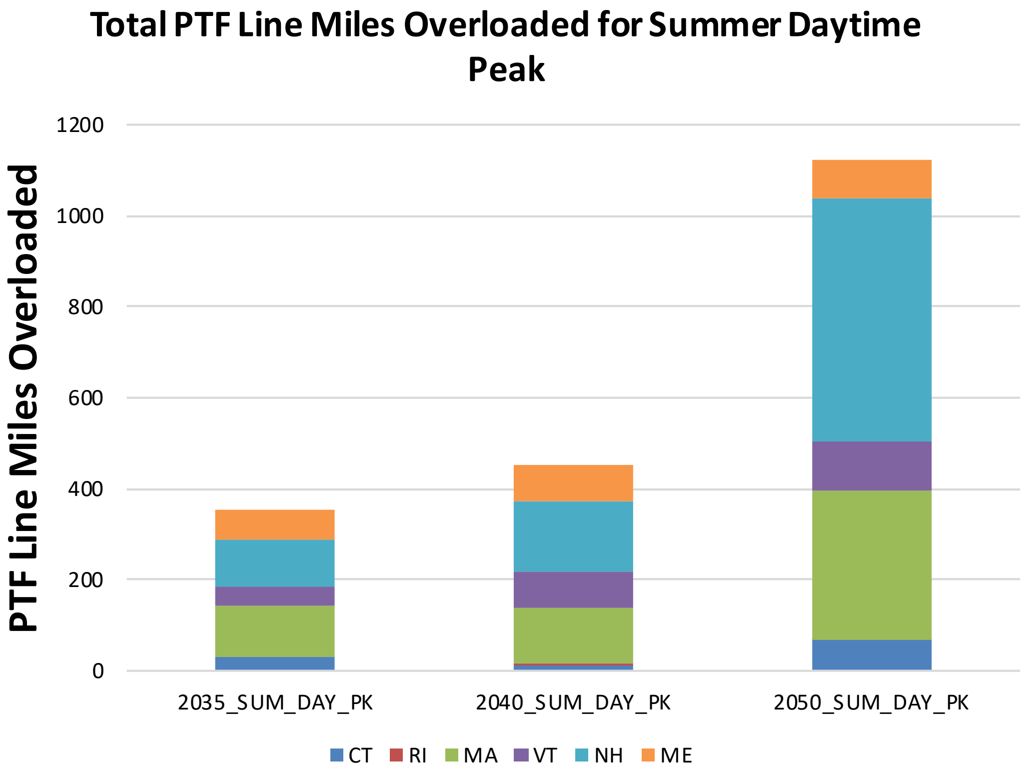
*The 2030 transfer levels from the FCA 16 Transmission Transfer Capability presentation are shown

**NY-NE uprated to 1,850 MW in this study

Note 1: Red = Exceeds current interface limits

Note 2: Non-NY imports were held constant in all cases at the levels specified in the 2050 Transmission Planning Study Scope of Work

Summer Daytime Peak Snapshot Results



	Number of Overloaded PTF Line Segments		
	2035	2040	2050
Total	50	59	136

Summer Daytime Peak Snapshot Observations

- Notes on generation and load assumptions
  - Closely matches the Summer Daytime Peak case from the Transmission Planning for the Clean Energy Transition (TPCET) in terms of renewable assumptions
  - Includes an increasing amount of transportation electrification load
  - Relies on an increasing amount of rooftop and ground mount PV
  - Excess resources in all cases
    - AC ties with NY are first reduced from 1,850 MW to as low as 0 MW
    - Natural gas generation is then reduced to achieve energy balance in snapshot
- Results show overloads in all New England states

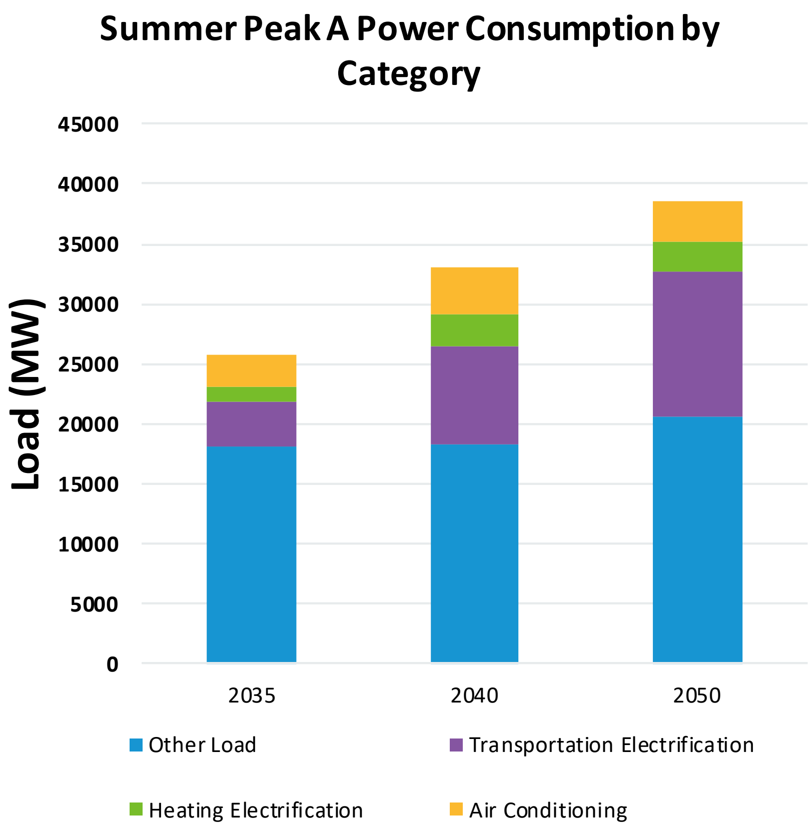
SUMMER EVENING PEAK SNAPSHOT

7 PM to 10 PM

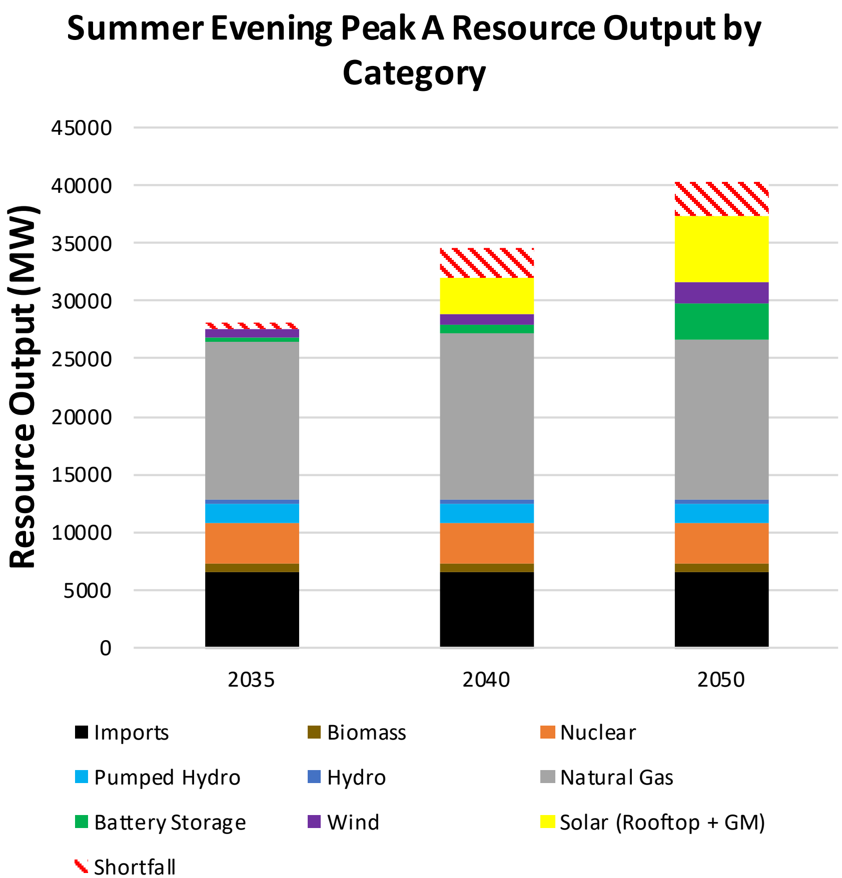
Summer Evening Peak A Snapshot

Application of the Load and Resource Assumptions

Load



Resources



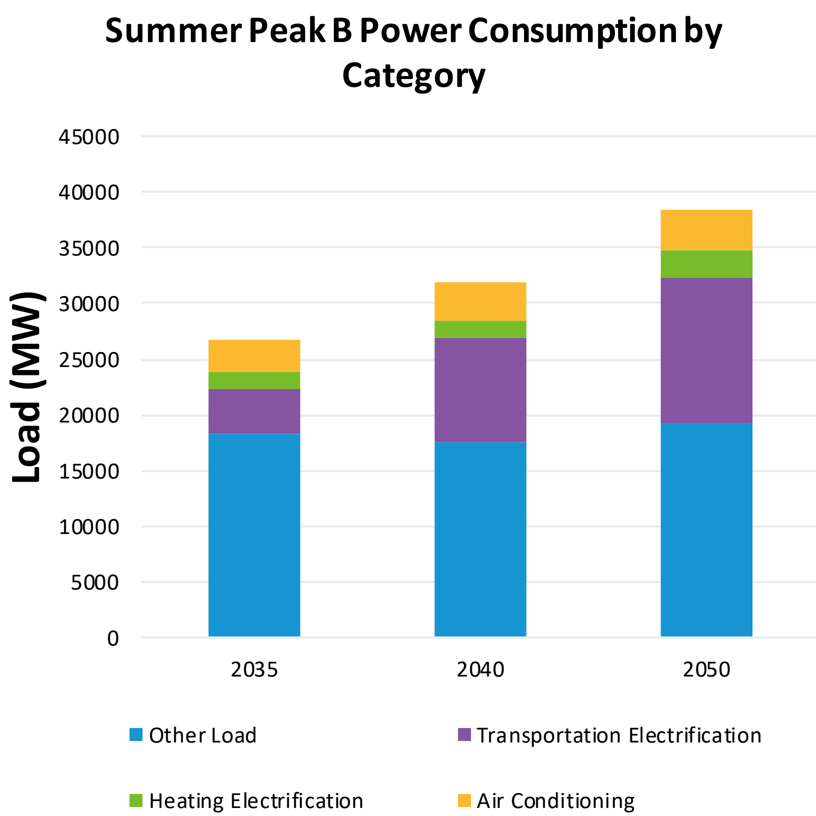
Note 1: Difference between load and generation is due to station service, mill loads and transmission losses

Note 2: The 2035 summer evening peak occurred after sunset so 0% solar availability was assumed. Due to differences in load shapes, the 2040 and 2050 summer evening peaks occurred slightly before sunset, so 10% solar availability was assumed.

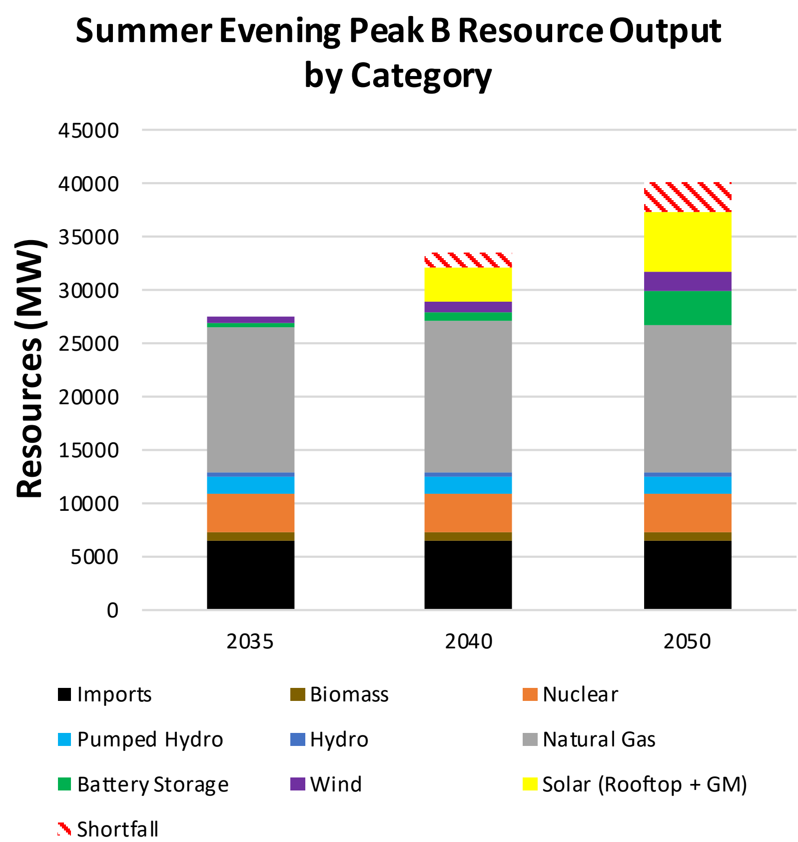
Summer Evening Peak B Snapshot

Application of the Load and Resource Assumptions

Load



Resources



Note 1: Difference between load and generation is due to station service, mill loads and transmission losses

Note 2: The 2035 summer evening peak occurred after sunset so 0% solar availability was assumed. Due to differences in load shapes, the 2040 and 2050 summer evening peaks occurred slightly before sunset, so 10% solar availability was assumed.

Summer Evening Peak A Snapshot Transfers

Interface	FCA 16 Transfer Capability (MW)*	2035 Snapshot (MW)	2040 Snapshot (MW)	2050 Snapshot (MW)
ME - NH	1,900	1,639	2,289	1,889
North - South	2,725	2,268	3,811	3,670
East - West	3,500	-1,697	-874	-1,556
West - East	3,000	1,697	832	1,551
SEMARI Export	3,400	290	515	789
Boston Import	5,250	4,133	4,612	5,172
CT Import	3,400	896	1,645	1,302
SWCT Import	2,800	2,634	3,428	3,059
NY-NE	1,400**	1,850	1,850	1,850

*The 2030 transfer levels from the FCA 16 Transmission Transfer Capability presentation are shown

**NY-NE uprated to 1,850 MW in this study

Note 1: Red = Exceeds current interface limits

Note 2: Non-NY imports were held constant in all cases at the levels specified in the 2050 Transmission Planning Study Scope of Work

Summer Evening Peak B Snapshot Transfers

Interface	FCA 16 Transfer Capability (MW)*	2035 Snapshot (MW)	2040 Snapshot (MW)	2050 Snapshot (MW)
ME - NH	1,900	1,194	1,259	1,125
North - South	2,725	1,483	2,270	2,050
East - West	3,500	-2,028	-1,905	-1,984
West - East	3,000	2,057	1,940	2,005
SEMARI Export	3,400	401	391	1,217
Boston Import	5,250	4,185	4,683	5,085
CT Import	3,400	156	488	560
SWCT Import	2,800	2,030	2,408	2,459
NY-NE	1,400**	1,501	1,850	1,850

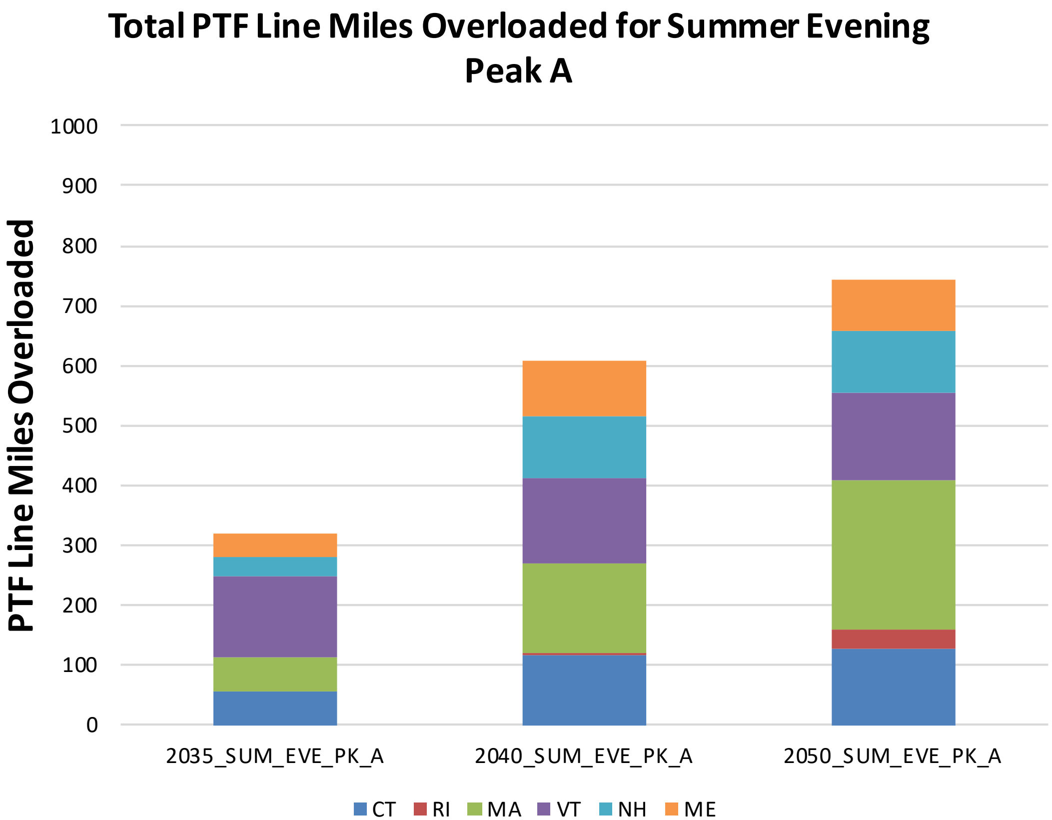
*The 2030 transfer levels from the FCA 16 Transmission Transfer Capability presentation are shown

**NY-NE uprated to 1,850 MW in this study

Note 1: Red = Exceeds current interface limits

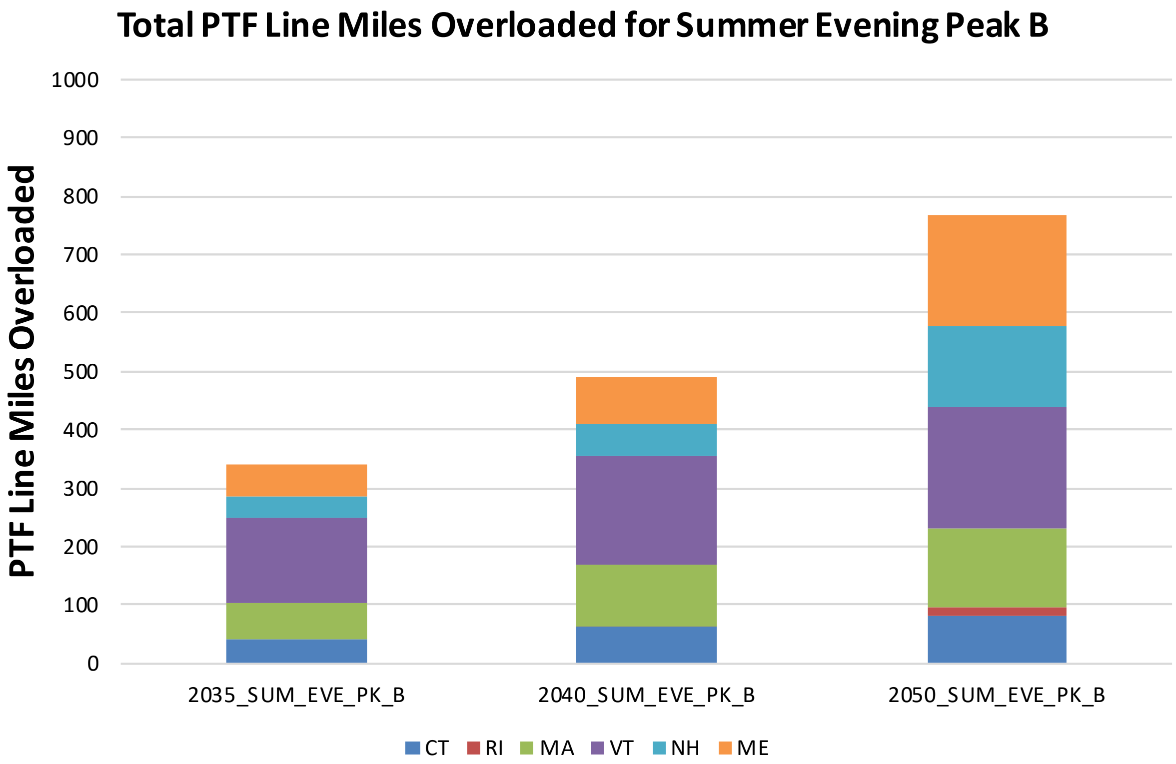
Note 2: Non-NY imports were held constant in all cases at the levels specified in the 2050 Transmission Planning Study Scope of Work

Summer Evening Peak A Snapshot Results



	Number of Overloaded PTF Line Segments		
	2035	2040	2050
Total	37	85	120

Summer Evening Peak B Snapshot Results



	Number of Overloaded PTF Line Segments		
	2035	2040	2050
Total	40	72	113

Summer Evening Peak Snapshot Observations

- Notes on generation and load assumptions
  - Closely matches the Summer Evening Peak case from the Transmission Planning for the Clean Energy Transition (TPCET) in terms of renewable assumptions
  - The rooftop and ground mount PV relied upon in the Summer Daytime Peak is replaced by dispatchable natural gas units and imports from NY
  - Insufficient resources to meet the power consumption requirements in all three years
    - Resources to meet the shortfall were assumed to be located at offshore wind interconnection points, either as BESS or as more offshore wind
- Summer Daytime Peak vs. Summer Evening Peaks
  - VT makes up a significant share of overloads in 2035 due to newly assumed HVDC line interconnecting at Coolidge 345 kV, but overloads do not increase significantly in VT in subsequent years
  - More overloads in the Evening Peak in 2040
  - By 2050, Summer Daytime Peak has significantly more overloads than Evening Peak
- Peak A vs. Peak B
  - As expected, more overloads are seen in the South for the coincident peak (peak A), and in the North for the non-coincident peak (peak B)

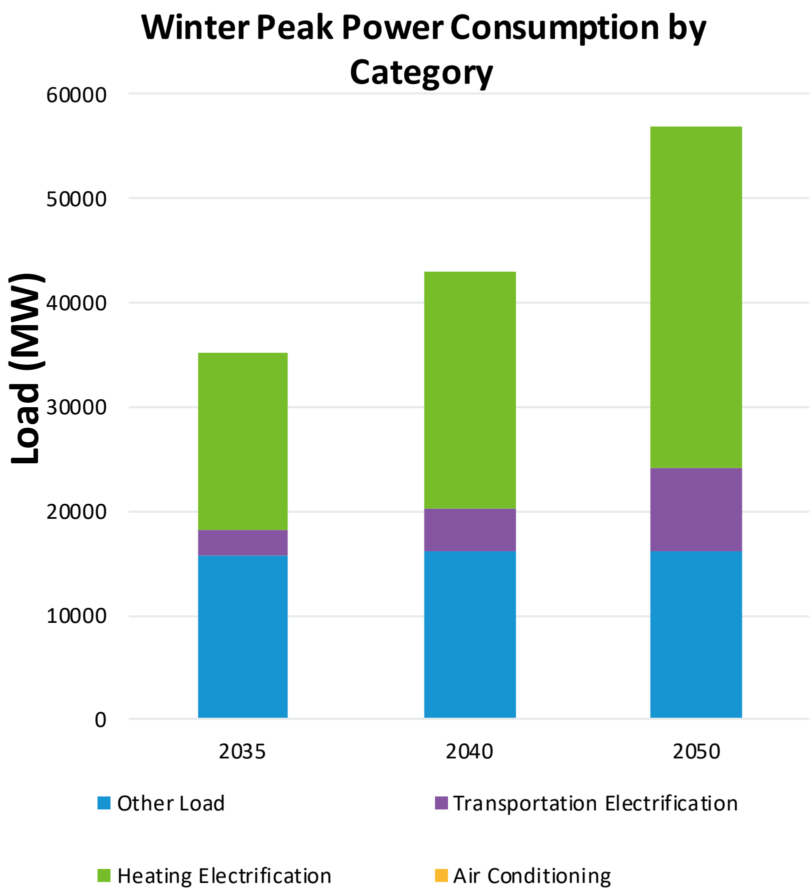
WINTER EVENING PEAK SNAPSHOT

4 PM to 10 PM

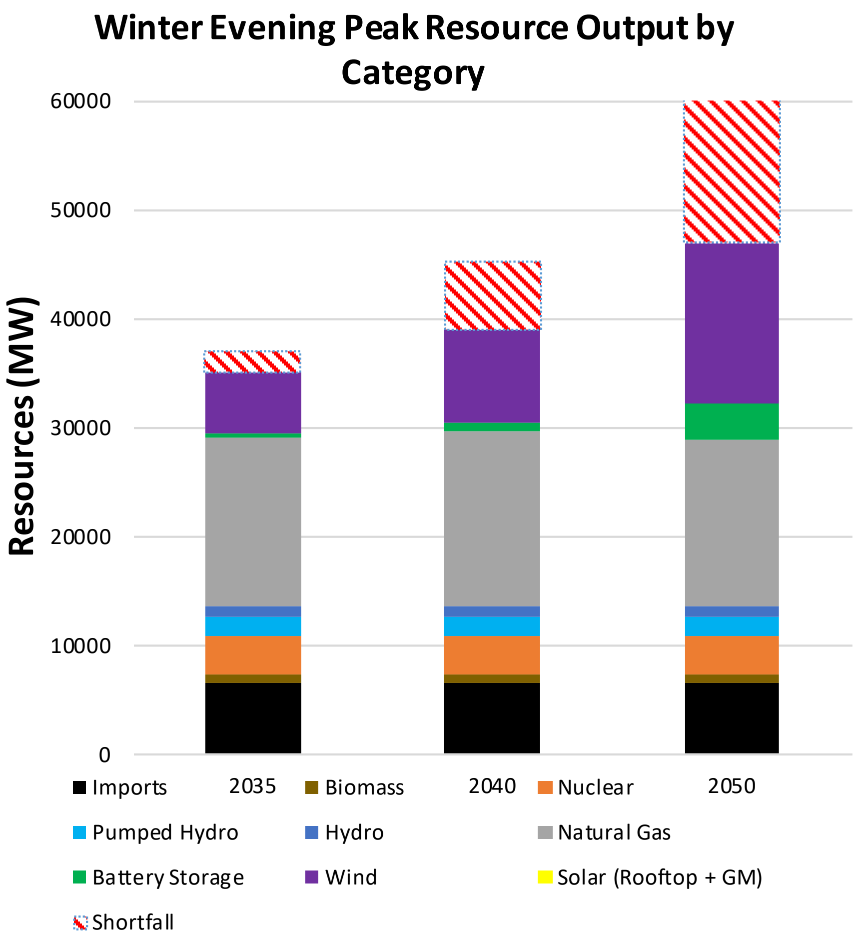
Winter Evening Peak Snapshot

Application of the Load and Resource Assumptions

Load



Resources



Note: Difference between load and generation is due to station service, mill loads and transmission losses

Winter Evening Peak Snapshot Transfers

Interface	FCA 16 Transfer Capability (MW)*	2035 Snapshot (MW)	2040 Snapshot (MW)	2050 Snapshot (MW)
ME - NH	1,900	2,746	3,718	6,090
North - South	2,725	2,985	4,093	5,672
East - West	3,500	-132	2,354	5,446
West - East	3,000	76	-2,465	-5,584
SEMARI Export	3,400	2,043	3,170	5,131
Boston Import	5,250	4,755	4,429	4,196
CT Import	3,400	1,822	3,221	4,770
SWCT Import	2,800	3,476	4,753	6,152
NY-NE	1,400**	1,850	1,850	1,850

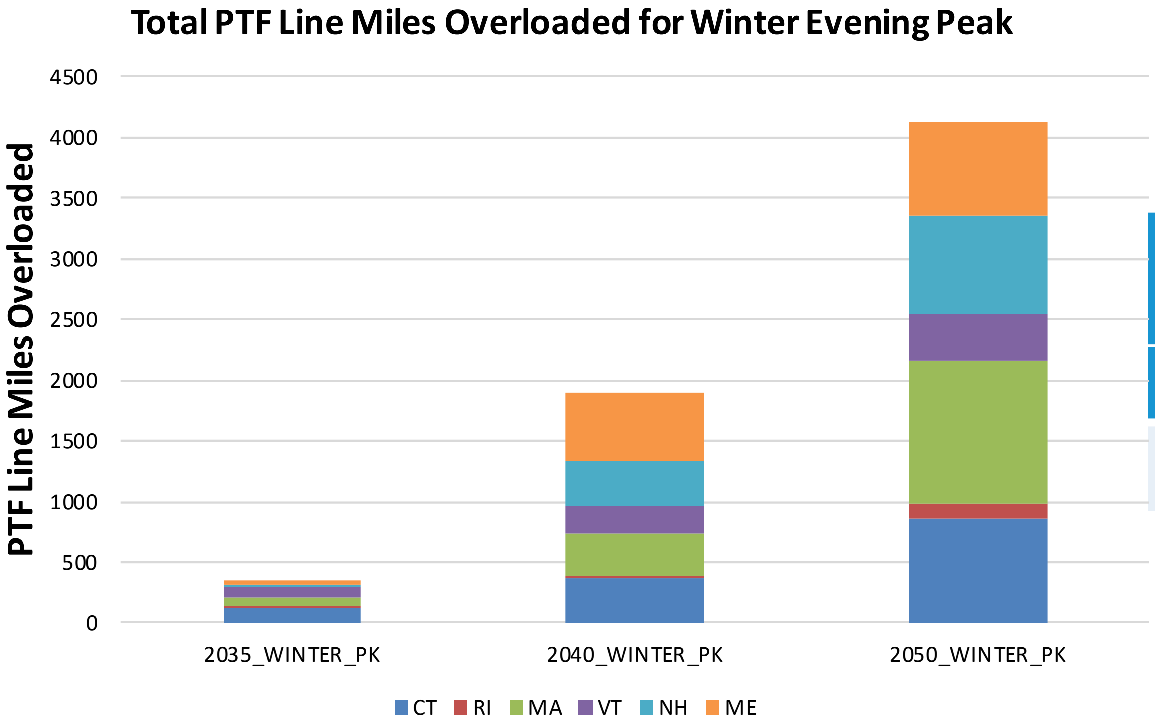
*The 2030 transfer levels from the FCA 16 Transmission Transfer Capability presentation are shown. Some limits are based on summer thermal ratings that would not apply during the winter season.

**NY-NE uprated to 1,850 MW in this study

Note 1: Red = Exceeds current interface limits

Note 2: Non-NY imports were held constant in all cases at the levels specified in the 2050 Transmission Planning Study Scope of Work

Winter Evening Peak Snapshot Results



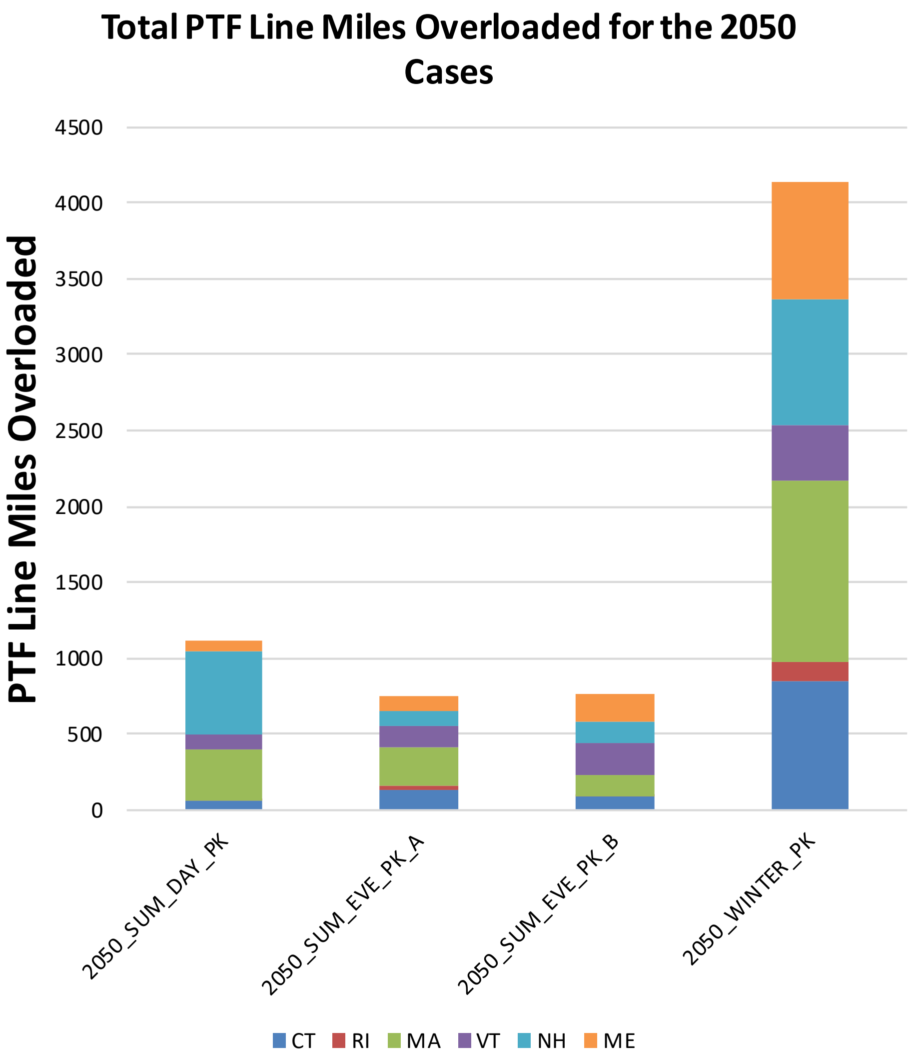
	Number of Overloaded PTF Line Segments		
	2035	2040	2050
Total	55	261	644

Winter Evening Peak Snapshot Observations

- Notes on generation and load assumptions
  - Significantly higher load than studied historically, largely due to growth of heating electrification
  - Solar is assumed to be zero as the snapshot occurs after sunset
  - Significant amount of wind generation online
  - Large amount of resource insufficiency (shortfall MWs) in all three years
    - Resources to meet the shortfall were assumed to be located at offshore wind interconnection points, either as BESS or as more offshore wind
- Results show significant overloads in all the New England states
  - From 2040 to 2050 there is a significant increase in overloads in MA, CT, and NH in particular

THERMAL RESULTS – SOME ADDITIONAL PERSPECTIVE

2050 Results by Case



- Within 2050, the vast majority of overloads occur in the Winter Evening Peak
- The Winter Evening Peak occurs rarely (only seen in one day based on All Options Pathways load data) but makes up most of the needed upgrades
- NH has a large percentage of the overloads in the Summer Day Peak

Overloads That Are Only Found in Summer Cases

State	Voltage	Miles Overloaded Only in Summer
ME	345 kV	0
	230 kV	0
	115 kV	68
NH	345 kV	0
	230 kV	265
	115 kV	108
VT	345 kV	0
	230 kV	0
	115 kV	0
MA	345 kV	23
	230 kV	0
	115 kV	74
RI	345 kV	0
	230 kV	0
	115 kV	1
CT	345 kV	0
	230 kV	0
	115 kV	5
Total		**544**

* With the exception of the 2035 Summer Evening Peak A and B

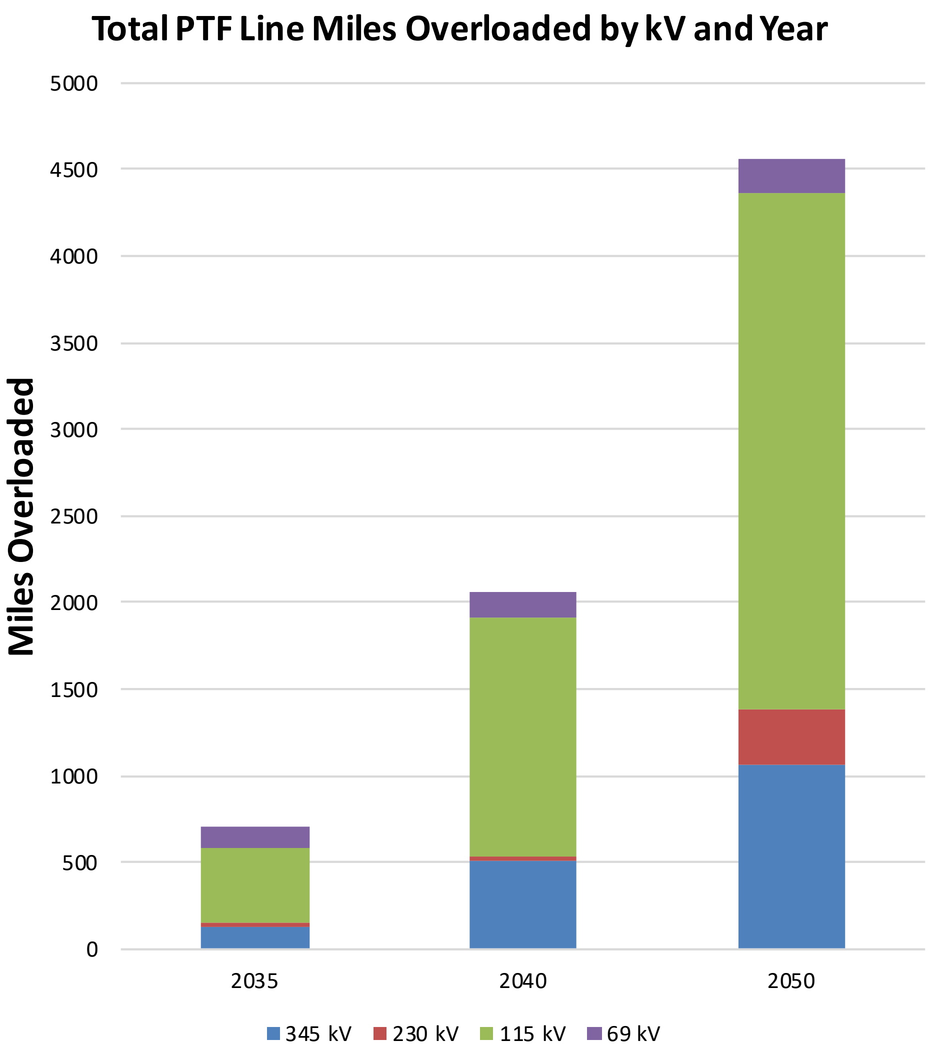
- 544 miles of overloads only occur in Summer cases, mostly in ME, NH, and MA
- These cases assume non-zero solar output*, unlike winter peak, so adjusting solar assumptions may have some impact here
- More analysis would be needed to determine if these can be mitigated via resource curtailment to reduce total number of miles needing to be upgraded

Overloads That Are Only Found in Winter Cases

State	Voltage	Miles Overloaded Only in Winter
ME	345 kV	321
	230 kV	0
	115 kV	210
NH	345 kV	72
	230 kV	0
	115 kV	410
VT	345 kV	0
	230 kV	0
	115 kV	92
MA	345 kV	206
	230 kV	18
	115 kV	628
RI	345 kV	9
	230 kV	0
	115 kV	89
CT	345 kV	181
	230 kV	0
	115 kV	469
Total		**2,705**

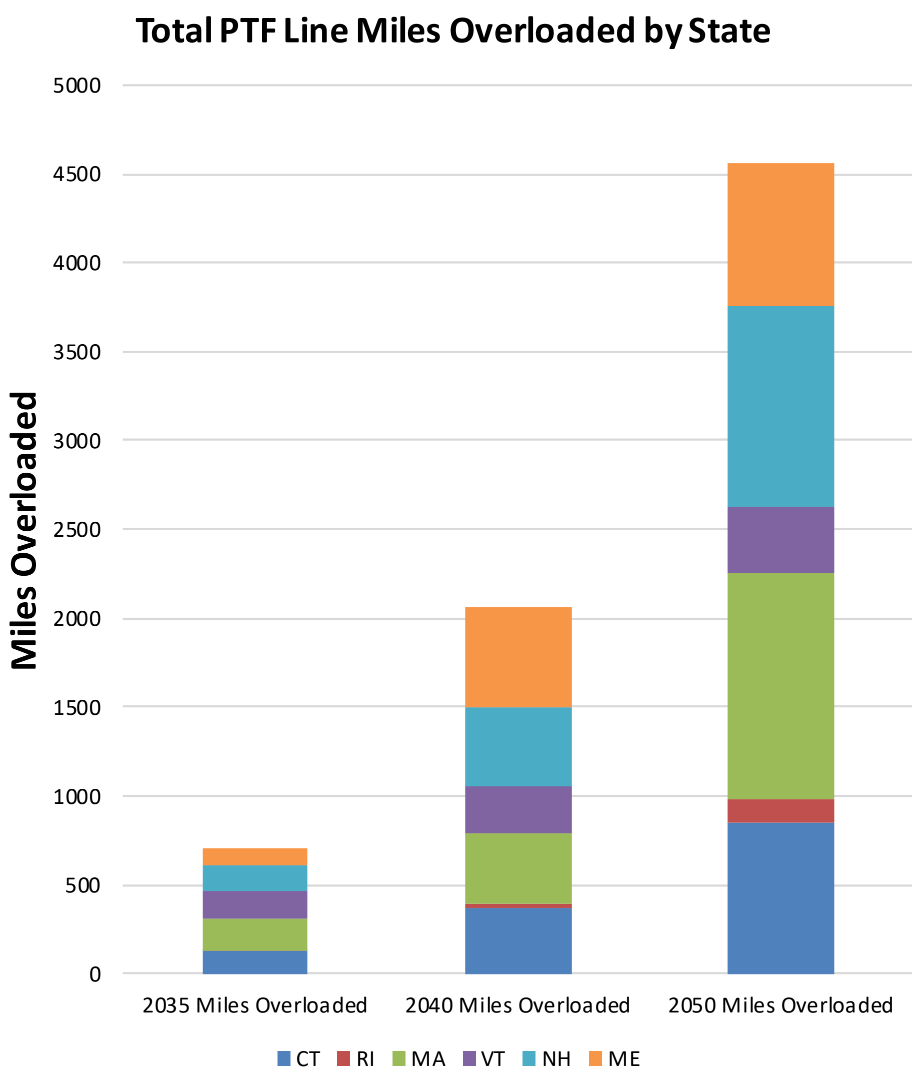
- 2,705 miles of overloads only occur in Winter cases
- These overloads are mostly driven by heating load and offshore wind
- More analysis would be needed to determine if these can be mitigated via load reduction to reduce total number of miles needing to be upgraded

Overloads by kV Level



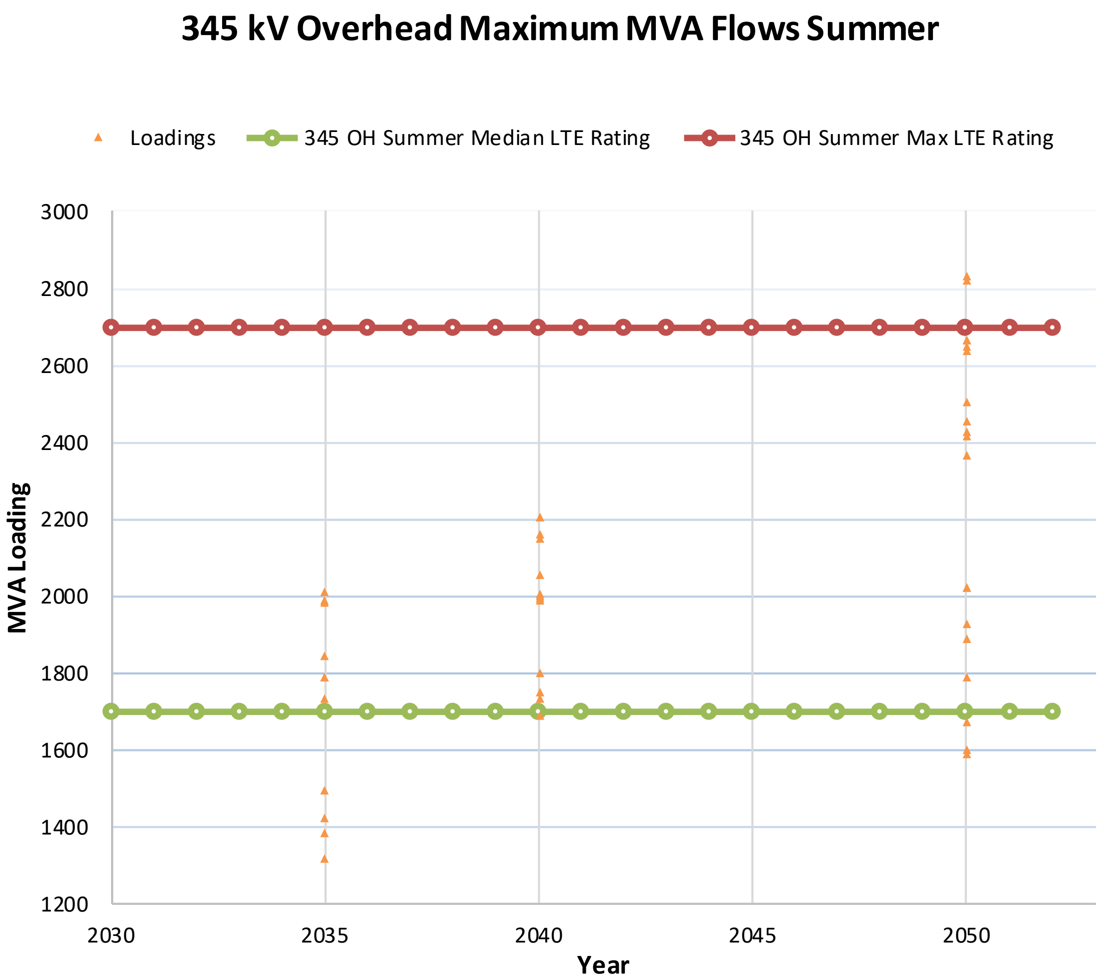
- The largest increase in overloaded miles between 2040 and 2050 is on the 115 kV system
- 115 kV system is generally associated with load-serving issues
- 345 kV system is generally associated with transfer issues
- 2050 load-serving issues mainly associated with large increase in heating electrification

Overloads by State



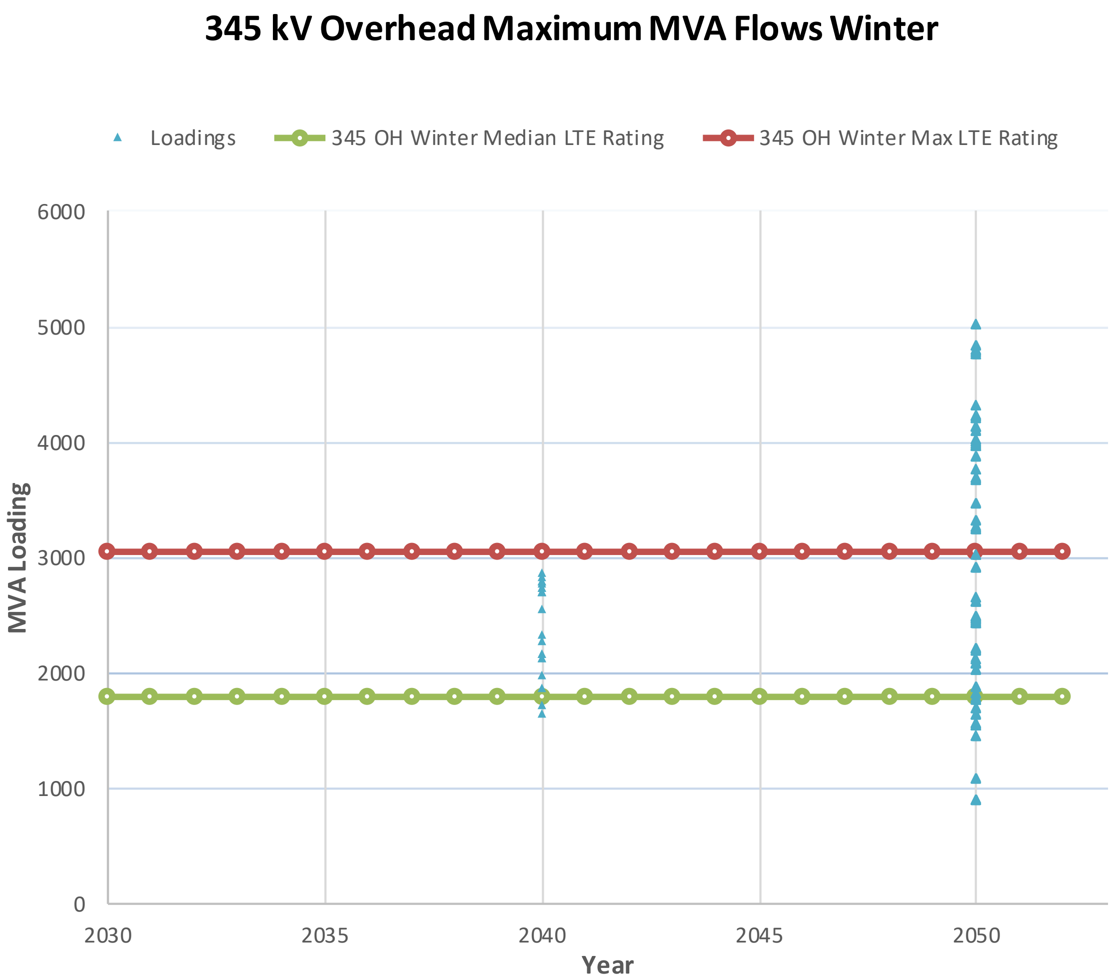
- In 2035 and 2040, most overloads are seen in the North, largely due to excess generation in northern NE
- Between 2040 and 2050 there is a large increase in miles overloaded in southern NE, particularly in MA, largely due to increased load

Severity of 345 kV Overloads for Summer



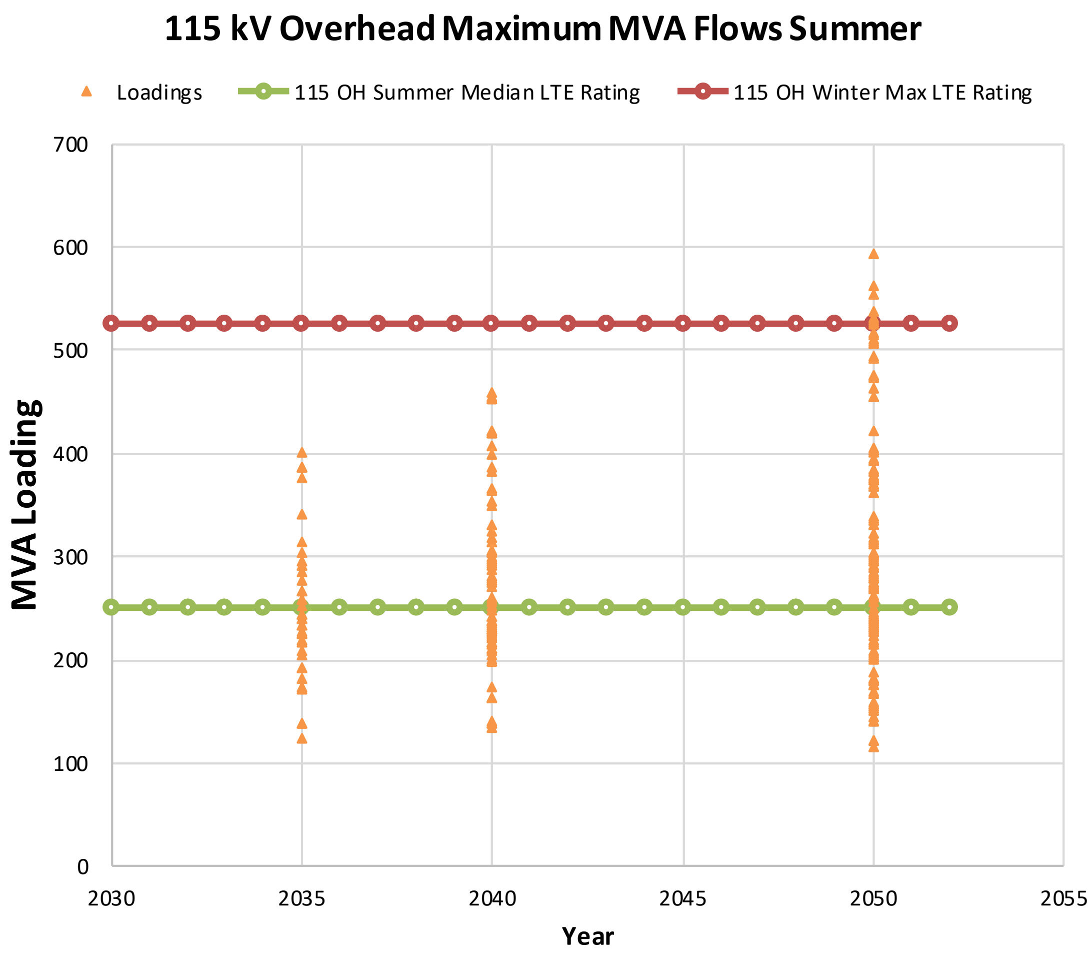
- Horizontal lines show maximum and median LTE ratings for most existing 345 kV lines
- Each triangle on the vertical line shows the maximum loading of one of the overloaded lines seen in the analysis
- Many overloads, particularly in 2050, exceed the summer median LTE rating
  - Rebuilding these lines can be expected to address the overloads (loading is below the red line representing maximum line rating)

Severity of 345 kV Overloads for Winter



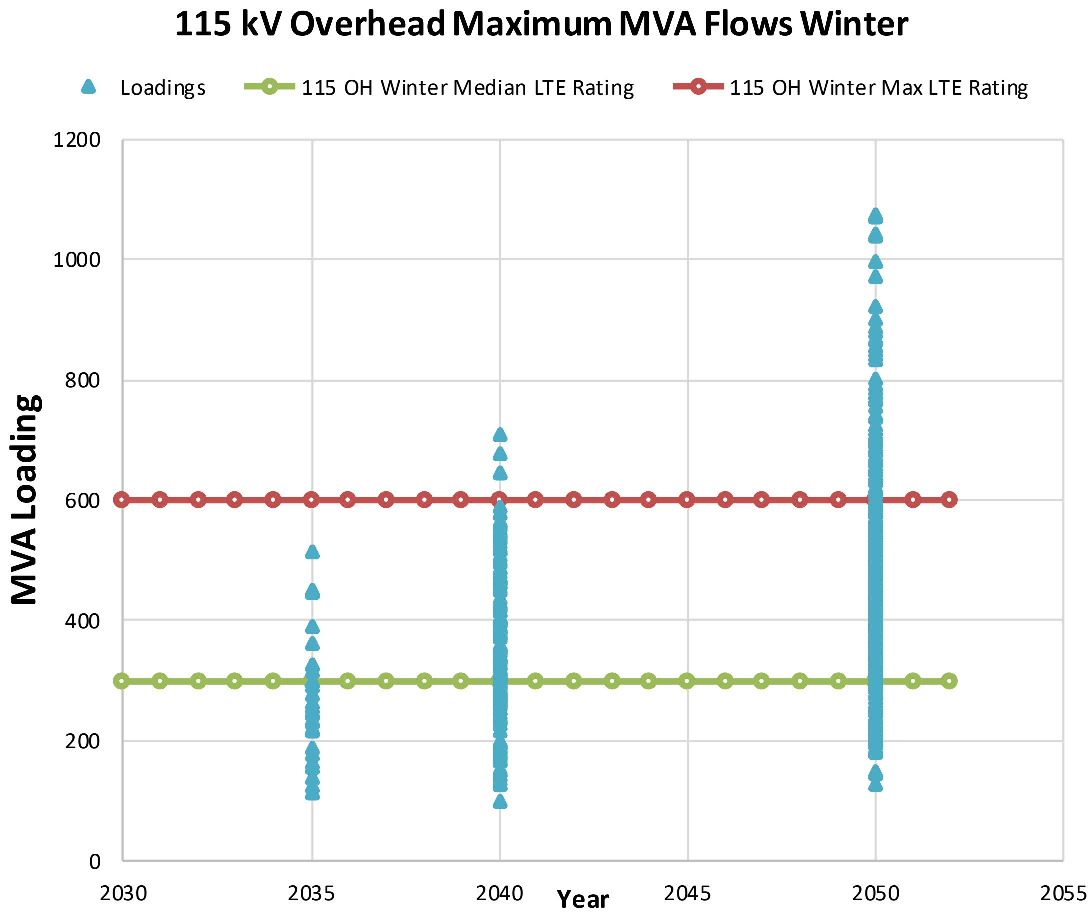
- There were no 345 kV overloads in 2035 for winter
- In 2040, all lines were below the winter maximum LTE rating, indicating that the lines may be able to be rebuilt to resolve the overloads
- By 2050, additional lines would likely be needed (many overloads exceed maximum winter LTE rating)

Severity of 115 kV Overloads for Summer



- 115 kV shows fairly similar distribution to 345 kV in terms of overloads

Severity of 115 kV Overloads for Winter



- In 2040, some 115 kV lines start to exceed the winter maximum LTE rating

Load vs. Generation in 2050 Summer Daytime Peak

State	Generation and Imports (MW)	Net Load (MW)	Excess Generation and Imports (MW)
ME	4660	2957	1703
NH	7068	3291	3777
VT	2393	1354	1039
North Total	**14121**	**7602**	**6519**
MA	11029	16316	-5287
RI	2187	2065	122
CT	8155	8934	-779
South Total	**21371**	**27315**	**-5944**

- Significant surplus of generation and imports in North, deficit in South
- Most surplus in this case comes from NH due to excess solar
- Large deficit in MA

Note 1: Differences in North and South excess generation and imports totals are due to losses
Note 2: A positive value in the Excess Generation and Imports column means surplus generation, a negative value means a generation deficit

Load vs. Generation in 2050 Winter Evening Peak

State	Generation and Imports (MW)	Net Load (MW)	Excess Generation and Imports (MW)
ME	12011	5359	6652
NH	5630	5147	483
VT	1862	2432	-570
North Total	**19503**	**12938**	**6565**
MA	23312	27091	-3779
RI	6781	3877	2904
CT	10618	14027	-3409
South Total	**40711**	**44995**	**-4284**

- Significant surplus of generation and imports in North, deficit in South
- Most surplus in this case comes from ME due to large amounts of wind
- Large deficit in MA and CT

Note 1: Differences in North and South excess generation and imports totals are due to losses
Note 2: A positive value in the Excess Generation and Imports column means surplus generation, a negative value means a generation deficit

KEY TAKEAWAYS

Key Takeaways

- The assumptions used for the 2050 Transmission Study represent numerous paradigm shifts for New England
  - Shift from a summer peaking area to a winter peaking area
  - Shift to increasing utilization of renewable resources
    - 56,665 MW of nameplate PV modeled in the 2050 snapshot
    - 34,960 MW of nameplate wind modeled in the 2050 snapshot
  - Electrification of heating and transportation more than doubles the amount of peak power consumption by 2050
- Achieving a load-generation balance with the input assumptions given requires:
  - The dispatch of fossil units for energy balance in all snapshots
  - The dispatch of all available non-reserve resources in 8 of the 12 snapshots
  - Additional resources beyond the input assumptions to meet the load in the Summer Evening and Winter snapshots
- Significant new transmission will be needed to reliably serve load under the assumptions analyzed in this study

Key Takeaways, cont.

- The Winter Peak in 2050 is the most challenging snapshot
  - The overloads are driven primarily by high heating load
  - Shortfalls in resources due to low resource availability require additional resources in all three snapshot years
  - The majority of the overloads come from the 2050 Winter Evening Peak snapshot, which occurs infrequently
- There are a significant number of overloaded miles that occur only in the winter or only in the summer snapshots
  - Further testing is underway to quantify the impact of resource assumptions
    - Summer may be able to be adjusted by changing solar assumptions (increasing/decreasing solar installations, or changing locational distribution)
    - Winter may be adjusted by changing wind and load assumptions

Key Takeaways, cont.

- With the current resource location assumptions, the paths between North and South would need significant upgrades to transfer surplus generation in Northern NE to generation-deficient Southern NE
  - Overloads on these 345 kV paths are high enough that slight adjustments to assumptions will not likely be enough to mitigate these violations
    - Relocating large amounts of generating resources from North to South may be helpful, although land requirements may make this infeasible
    - Another option may be to put more offshore wind in the south and start moving the interconnection points further inland as many of the coastal stations already have as much wind as they can handle
  - Rebuilding many of these lines will not be sufficient to fix the overloads that are higher than the maximum line ratings

NEXT STEPS

Feedback and Next Steps

- Feedback on the 2050 Transmission Study presentation and detailed results may be submitted to pacmatters@iso-ne.com by March 30, 2022
- Next Steps:
  - Run sensitivities on 2050 Winter Peak to establish the relationship between load level and overloads
  - Perform further analysis to determine if summer-only overloads can be solved via different solar resource distributions
  - Begin development of possible transmission solutions

Questions