Offshore Transmission in New England: Benefits of a Better Planned Grid

Appendix B

Transmission Security Analysis & Economic Production Cost Simulation

GE Energy Consulting for Anbaric

August 4, 2020

Overview of Planning Study Process & Methodology

Transmission Security Analysis

Purpose: Model and Evaluate Costs of Current vs. Planned Transmission Development for ISONE Offshore Wind

Modify ISONE Cases to Create OSW Buildout Base Cases(PSSE)

» Scenario 1: Current HVAC Transmission Buildout

» Scenario 2: Planned HVDC Transmission Buildout + Mystic Reliability Wind Link Project

Perform Transmission Security Analysis (TARA)

» NERC Transmission Planning Performance Requirements TPL-001-4

» NPPC Directory #1: Design and Operation of Bulk Power System

Economic Study Process & Methodology

Purpose: Compare Economic Production Cost Metrics in Current vs. Planned Transmission

Build[1] GE EC MAPS 4-Pool Database Model (PJM/NYISO/IESO/ISONE)

» Base Case: Install 3.1 GW of Baseline OSW in ISONE
» Scenario 1: Current HVAC Transmission Buildout (8.1 GW OSW)
» Scenario 2: Planned HVDC Transmission Buildout (8.6 GW OSW) + Mystic Reliability Wind Link Project

Base Case Assumption: Six Transmission Upgrades

» Upgrades assumed as necessary to address 44% curtailment resulting from Base Case injections

Scenario 1 & 2 Include Reliability Upgrades from Base Case Injections

» Necessary transmission upgrades to meet NERC TPL Standards / NPCC Directory 1 Requirements

Key Production Cost Simulation Metrics for ISONE

» Offshore Wind Curtailment (%)
» Annual Average LMP ($/MWh)
» Annual Production Cost Savings ($M)
» Load Payment Savings ($M)

[1] https://www.iso-ne.com/static-assets/documents/2019/05/a2_2019_economic_study_draft_scope_of_work_and_high_level_assumptions.pptx

Overview of Economic Study Process & Methodology

Comparison to ISONE Economic Study Methodology[1]

GE EC Anbaric Study

More granular and closely mirrors modeling new transmission overloads needed to be addressed to interconnect offshore wind

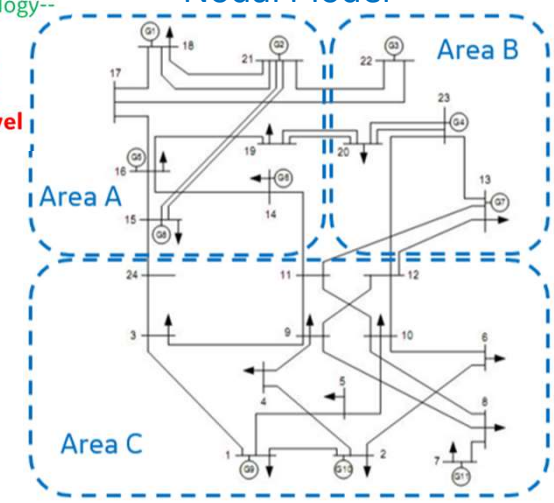
» Network Topology – Nodal model allows detailed specific N-1 transmission contingency constraints

» Transmission Constraints (Current) – Interface transfer limits *and* specific transmission element constraints (N-0 and N-1)

» Transmission Constraints (Offshore Wind Buildout) – Model additional constraints (N-0 and N-1) based on updated power flow analysis to more accurately capture future congestion patterns

- ISO Commitment & Dispatch Operations Modeling Methodology-- Uses AC Powerflow Data
- Monitor and Secures Flows on Individual Lines and Interfaces
- **Different Prices at Nodal Level**

Nodal Model



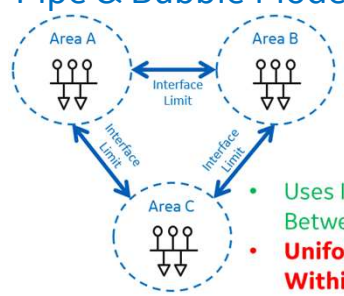
ISONE Economic Study

» Network Topology – Pipe and bubble model

» Transmission Constraints (Current) – Model interface transfer limits only

» Transmission Constraints (Offshore Wind Buildout) – None, only models existing interfaces

Pipe & Bubble Model



- Uses Interface Limits Between Areas
- **Uniform Price Within an Area**

[1] https://www.iso-ne.com/static-assets/documents/2020/02/a6_nescoe_2019_Econ_8000.pdf

Offshore Wind Point-of-Interconnection List

Scenario 1 AC vs Scenario 2 HVDC Buildout

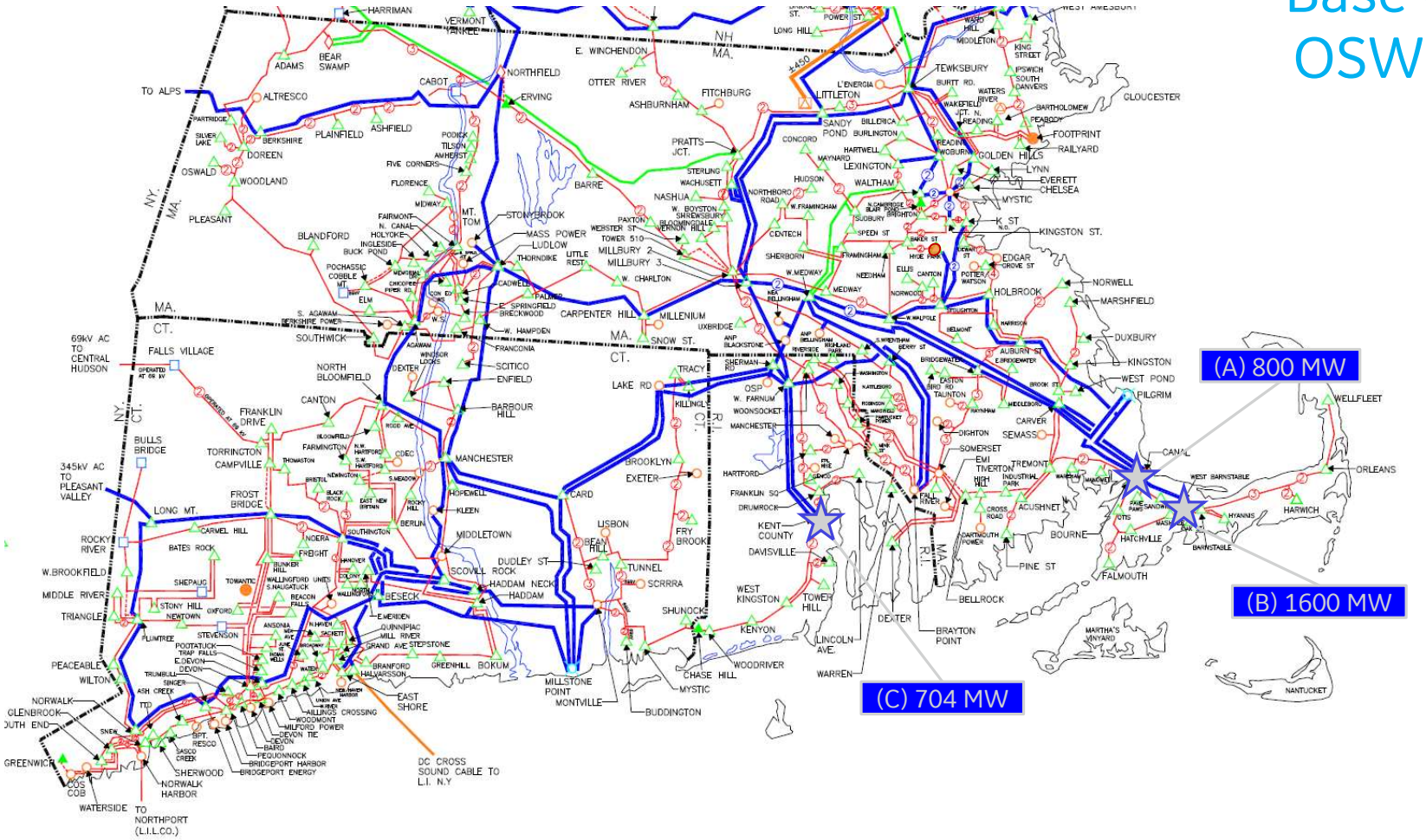
**Baseline 800 MW at Bourne 345 kV POI modeled at Canal 345 kV & Bourne 115 kV			Additional MWs Added to Baseline				
POI Substation Name	**Bus Number**	**Baseline Offshore Wind**	**Scenario 1: Current - Radial AC**		**Scenario 2: Planned - Offshore HVDC Grid**		
			Phased 2024	**Full 2028**	**Phased 2024**	**Full 2028**	
Footprint (Salem Harbor 115kV)	114417						***POWER INJECTION AT POI (MW)***
Woburn 345 kV	110756					800	
Mystic 345 kV	110759				1200	1200	
K Street 345 kV	110790					800	
Bridgewater 345 kV	115446					970	
Pilgrim (alternate to Footprint) 115 kV	110783						
Canal 345 kV	111193	600**	1100	2500			
West Barnstable 345 kV	111134	1600					
Bourne 115 kV	111217	200**	100	445			
Brayton Point 345 kV	114734		800	800	1200	1200	
Kent County 345 kV	117301	704	800	2200		418	
Montville 345 kV	119180		800	2200			
Millstone/WaterfordCT 345 kV	119194					1200	
New Haven (alternate to Kent Co)							
East Devon 345 kV	119389					800	
Singer/BridgeportCT 345 kV	123626				1200	1200	
Incremental MW Total to Onshore POIs		**3104**	**3600**	**8145**	**3600**	**8588**	
POIs		2	5	5	3	9	

Phased 2024 reflects next procurement round based on existing authorizations for MA (1600 MW), CT (1200 MW) and additional demand from other New England states and third parties

Full 2028 reflects development of full 14.5 GW estimated capacity of ISONE offshore lease areas. 2028 was chosen to remain within ISONE projections. Injection volumes in 2028 were based on assumed losses of 8% for Scenario 1 and 3% for Scenario 2. Subsequent revision of assumed losses to 4% for Scenario 1 and 2.4% for Scenario 2 would increase total 2028 injections to 8,499MW for Scenario 1 and 8,641MW for Scenario 2. Larger additional injections in Scenario 1 are not anticipated to change results significantly, as marginal injections at constrained POIs would have minimal system-wide impacts.

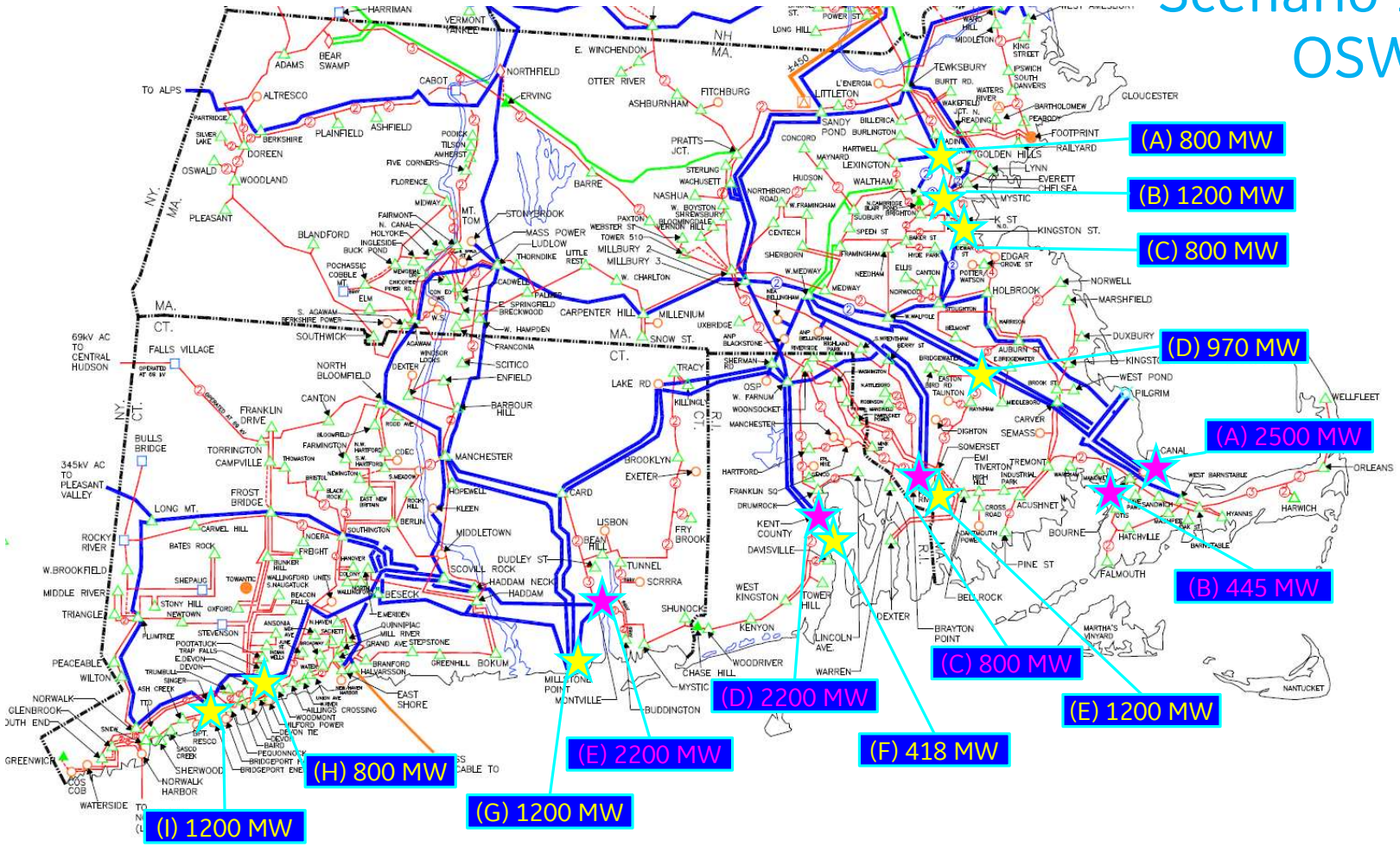
Millstone 1200 MW assumes continuing operation of Millstone Nuclear Plant in 2030, retirement of Unit 2 or 3 could enable additional offshore wind injection

Base Case Baseline OSW Buildout Map



- ☆ Baseline POI
- » 3.104 GW
- » 3 POIs:
  - A. Bourne 345 kV
  - B. W. Barnstable 345 kV
  - C. Kent County 345 kV

Scenario 1 vs Scenario 2 OSW Buildout Map



Scenario 1 POI

- » 8.145 GW
- » 5 POI
  - A. Canal 345 kV
  - B. Bourne 345 kV
  - C. Brayton Point 345 kV
  - D. Kent County 345 kV
  - E. Montville 345 kV

Scenario 2 POI

- » 8.588 GW
- » 9 POI
  - A. Woburn 345 kV
  - B. Mystic 345 kV
  - C. K Street 345 kV
  - D. Bridgewater 345 kV
  - E. Brayton Point 345 kV
  - F. Kent County 345 kV
  - G. Millstone 345 kV
  - H. East Devon 345 kV
  - I. Singer 345 kV

Transmission Security Results

TARA Contingency Analysis

- N-1
- N-1-1

N-1 Results

TARA Contingency Analysis

Overloaded Monitored Elements in Scenario 1 *Phased* OSW Buildout (2024)

Overloaded Transmission Elements (27)

- New Overloads (10)
- Overloaded in Base Case AND OSW (13)
- Overloaded in Base Case, Worse in OSW (4)

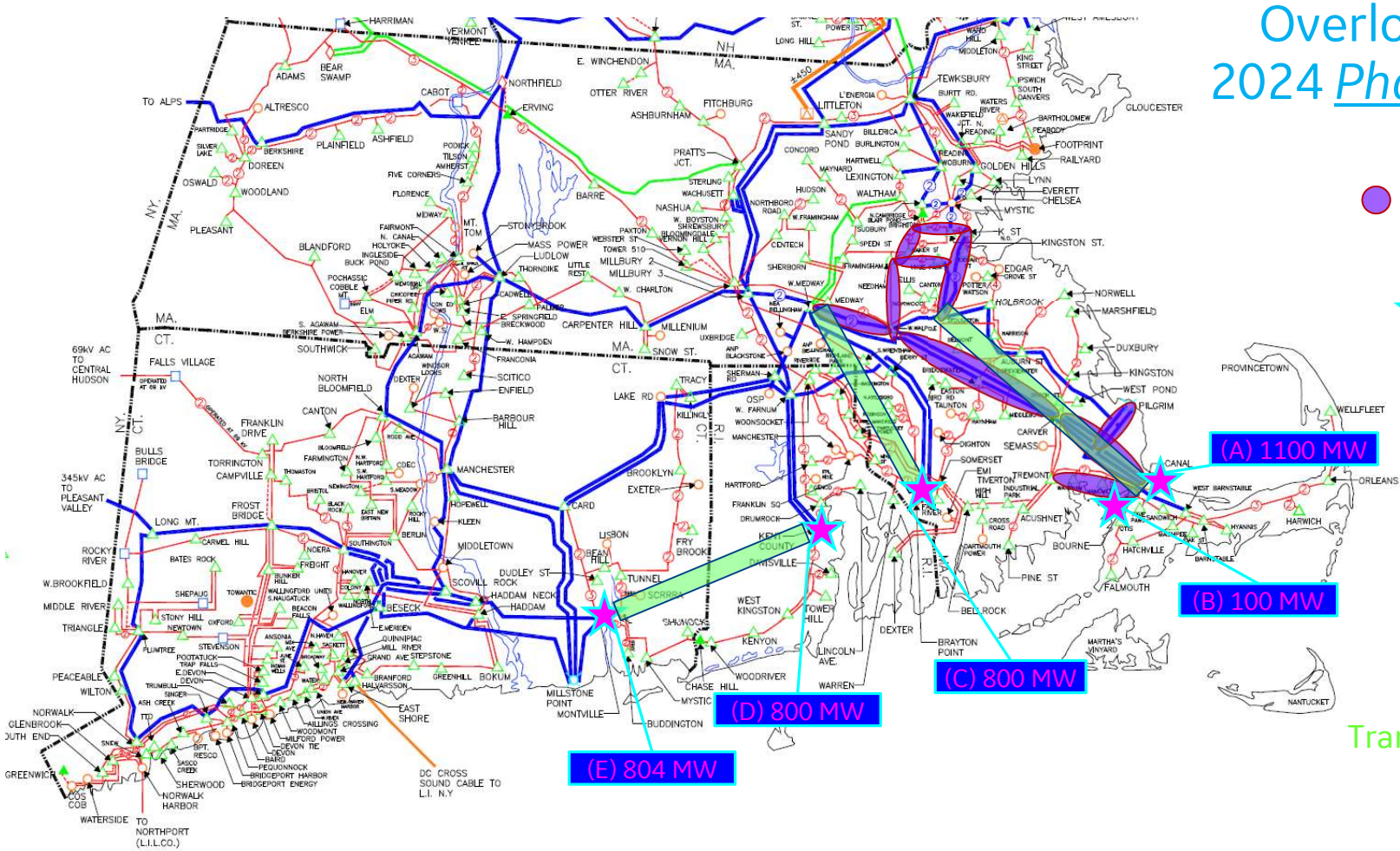
Overloaded Transmission Elements by kV:

- 345 kV Branches (11)
- 115 kV Branches (29)

Monitored Facility	kV	2024 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency	Mitigated by Transmission Project
111133 CARVER 345 111193 CANAL 345 1	345	143	< 85%	1221	5	A
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	115	129	< 85%	150	251	NONE
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	115	129	< 85%	150	251	NONE
110782 JORDAN ROAD 345 111193 CANAL 345 1	345	128	< 85%	1446	5	A
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	115	123	< 85%	150	386	NONE
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	115	123	< 85%	150	386	NONE
111133 CARVER 345 111134 W BARNSTABLE 345 1	345	118	< 85%	1016	259	NONE
110853 COLBURN 511 115 110855 WASH_TAP 511 115 1	115	118	99	140	1	NONE
110852 COLBURN 510 115 110854 WASH_TAP 510 115 1	115	118	99	140	1	NONE
110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	115	114	95	205	9	NONE
110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	115	114	95	205	9	NONE
111133 CARVER 345 115013 NGR_356_NST 345 1	345	112	< 85%	1410	8	A
110786 STOUGHTON 345 110790 K STREET 1 345 2	345	111	< 85%	675	9	NONE
110786 STOUGHTON 345 110790 K STREET 1 345 1	345	110	91	675	5	NONE
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	115	109	< 85%	246	3	A
111133 CARVER 345 115036 NGR_331_NST 345 1	345	104	< 85%	1156	4	A
110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	345	104	< 85%	1156	4	A
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	115	103	< 85%	246	2	A
111158 HORSEPDTP113 115 111217 BOURNE 115 1	115	103	< 85%	246	2	A
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	115	101	< 85%	246	2	A
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	115	100	< 85%	246	2	A
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	115	100	< 85%	246	2	A
111149 HORSEPDTP108 115 111217 BOURNE 115 1	115	101	88	354	1	A
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	115	137	118	235	1	NONE
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	115	136	116	235	1	NONE
110893 NEEDHAM 115 110894 DOVER MA 115 1	115	115	108	385	5	NONE
111137 TREMONT S 115 111155 WAREHAM 108 115 1	115	119	102	246	1	A

Transmission Project Code:
A) Canal - Stoughton 345 kV
B) Brayton Point - West Medway 345 kV
C) Monvale - Kent County 345 kV

Overloaded Elements
2024 *Phased* Scenario 1



- Design Contingency
- Scenario 1 POI 3.6 GW
  - » 5 POI
    - A. Canal 345 kV
    - B. Bourne 345 kV
    - C. Brayton Point 345 kV
    - D. Kent County 345 kV
    - E. Montville 345 kV

Potential 345kV Transmission Reinforcements Identified by ISONE

Overloaded Monitored Elements in Scenario 1 *Full* OSW Buildout (2028)

Overloaded Transmission Elements (60)

- New Overloads (42)
- Overloaded in Base Case AND OSW (17)
- Overloaded in Base Case, Worse in OSW (1)

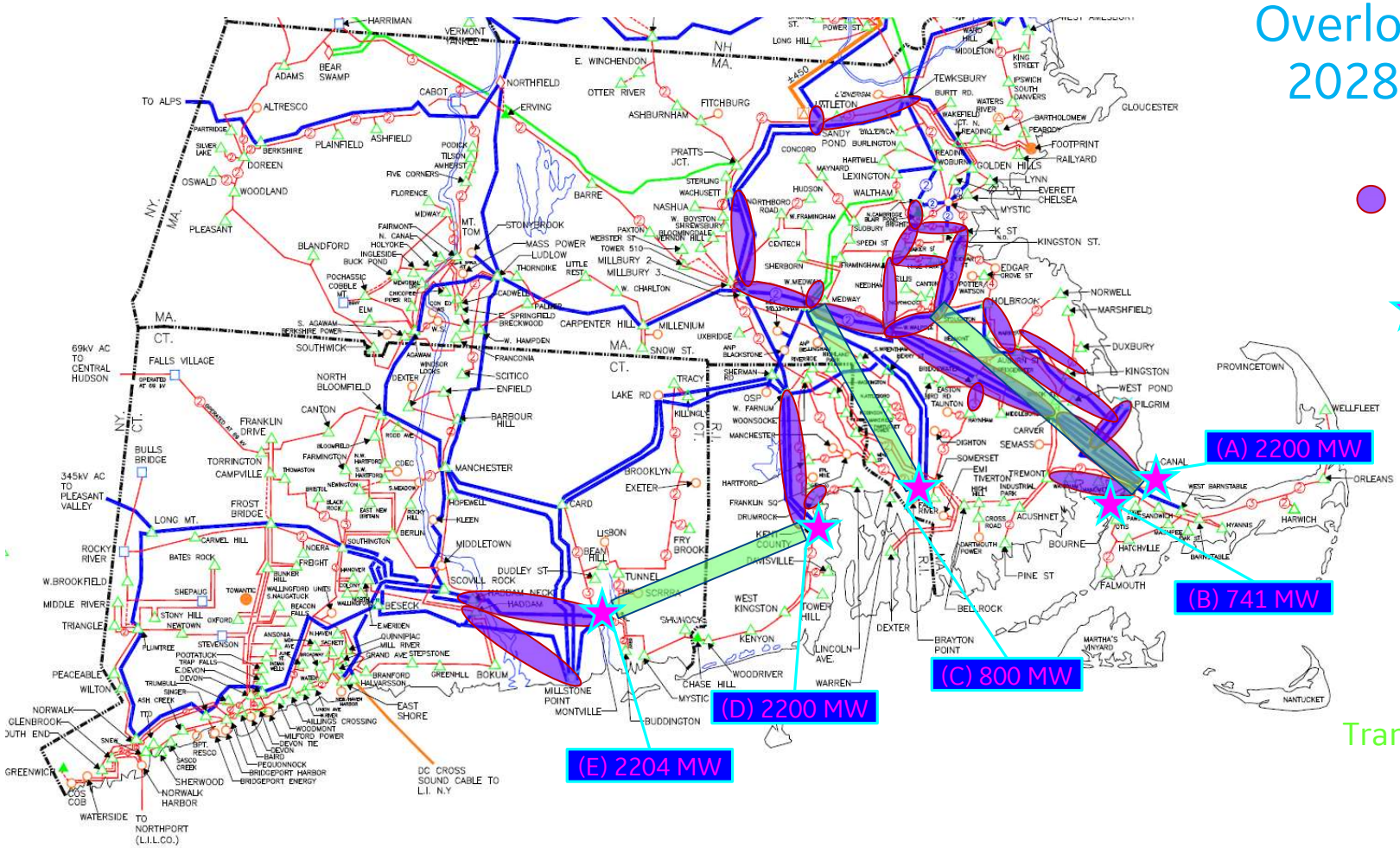
Overloaded Transmission Elements by kV:

- 345 kV Branches (22)
- 115 kV Branches (32)
- Transformers (6)

Transmission Project Code:
A) Canal - Stoughton 345 kV
B) Brayton Point - West Medway 345 kV
C) Monvale - Kent County 345 kV

Monitored Facility	kV	2028 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency	Mitigated by Transmission Project
111133 CARVER 345 111193 CANAL 345 1	345	217	< 85%	1221	33	A
110782 JORDAN ROAD 345 111193 CANAL 345 1	345	192	< 85%	1446	888	A
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	115	171	< 85%	150	372	NONE
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	115	170	< 85%	150	371	NONE
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	115	165	< 85%	246	58	A
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	115	158	< 85%	246	11	A
111158 HORSEPDTP113 115 111217 BOURNE 115 1	115	158	< 85%	246	11	A
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	115	157	< 85%	246	8	A
111133 CARVER 345 115013 NGR_356_NST 345 1	345	156	< 85%	1410	847	A
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	115	156	< 85%	246	9	A
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	115	156	< 85%	246	9	A
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	115	152	< 85%	150	303	NONE
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	115	152	< 85%	150	303	NONE
111137 TREMONT S 115 111155 WAREHAM 108 115 1	115	148	< 85%	246	5	A
111133 CARVER 345 115036 NGR_331_NST 345 1	345	144	< 85%	1156	22	A
110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	345	144	< 85%	1156	22	A
110852 COLBURN 510 115 110854 WASH_TAP 510 115 1	115	141	99	140	1	NONE
110853 COLBURN 511 115 110855 WASH_TAP 511 115 1	115	141	99	140	1	NONE
110781 HOLBROOK 345 115009 NGR_335_NST 345 1	345	139	< 85%	1410	35	A
110786 STOUGHTON 345 110790 K STREET 1 345 2	345	138	< 85%	675	893	NONE
110786 STOUGHTON 345 110790 K STREET 1 345 1	345	137	< 85%	675	17	NONE
110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	115	136	< 85%	205	359	NONE
110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	115	136	< 85%	205	359	NONE
110782 JORDAN ROAD 345 115011 NGR_342_NST 345 1	345	132	< 85%	1855	11	A
110834 HIGH ST 510 115 110836 K STREET 1 115 1	115	130	< 85%	190	45	NONE
110835 HIGH ST 511 115 110837 K STREET 2 115 1	115	129	< 85%	190	48	NONE
111133 CARVER 345 111134 W BARNSTABLE 345 1	345	129	< 85%	1016	100	NONE
110830 KINGSTN ST W 115 110836 K STREET 1 115 2	115	125	< 85%	190	29	NONE
111136 KINGSTON 115 115006 NGR_191_NST 115 1	115	124	< 85%	165	2	NONE
110830 KINGSTN ST W 115 110836 K STREET 1 115 1	115	124	< 85%	190	29	NONE
115446 BRIDGEWATER 345 115451 BRIDGEWATER 115 2	345	122	< 85%	472	1	A
111149 HORSEPDTP108 115 111217 BOURNE 115 1	115	121	< 85%	354	4	A
110772 W MEDWAY B 345 115014 NGR_357_NST 345 2	345	118	< 85%	1315	1	NONE
119168 HADDAM NECK 345 119180 MONTVILE_364 345 1	345	118	< 85%	1884	8	C
110836 K STREET 1 115 110790 K STREET 1 345 1	345	117	< 85%	750	7	NONE
110837 K STREET 2 115 110790 K STREET 1 345 1	345	117	< 85%	750	8	NONE
115011 NGR_342_NST 345 115447 AUBURN ST 345 1	345	116	< 85%	2108	5	A
110814 BRIGHTON B 115 110815 N. CAMBRIDGE 115 1	115	114	< 85%	231	4	NONE
115008 NST_331_NGR 345 115036 NGR_331_NST 345 1	345	113	< 85%	1466	8	A
115446 BRIDGEWATER 345 115451 BRIDGEWATER 115 1	345	112	< 85%	515	1	A
110813 BRIGHTON A 115 110989 BLAIR POND 115 1	115	111	< 85%	231	1	NONE
113950 SANDY POND 345 114027 SANDY PD T1 99.0 1	345	111	86	572	1	NONE
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	115	110	< 85%	235	3	NONE
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	115	110	< 85%	235	3	NONE
113264 MILLBURY 345 113265 WACHUSETT 345 1	345	108	< 85%	1609	1	NONE
110900 HOLBROOK 115 110908 E.HOLBRK TAP 115 1	115	107	< 85%	548	2	A
119194 MILLSTONE 345 119209 HADDAM 345 1	345	107	< 85%	1884	6	C
110791 HYDE PARK 115 110788 HYDE PARK 345 1	345	107	89	600	8	NONE
117001 WEST FARNUM 345 117301 KENT COUNTY 345 2	345	107	< 85%	1918	4	C
113950 SANDY POND 345 113951 TEWKSBURY 345 1	345	107	< 85%	1918	6	NONE
110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	345	107	< 85%	585	9	NONE
117330 JOHNSTON_171 115 117334 RISE 171_TAP 115 1	115	106	< 85%	446	2	B
117001 WEST FARNUM 345 117301 KENT COUNTY 345 1	345	106	< 85%	1918	4	C
110832 KINGSTN ST A 115 110835 HIGH ST 511 115 1	115	106	< 85%	190	4	NONE
110833 KINGSTN ST B 115 110834 HIGH ST 510 115 1	115	105	< 85%	190	4	NONE
110781 HOLBROOK 345 110786 STOUGHTON 345 1	345	105	< 85%	1649	1	A
115013 NGR_356_NST 345 115446 BRIDGEWATER 345 1	345	104	< 85%	2108	4	A
110908 E.HOLBRK TAP 115 115020 NG451-536NST 115 1	115	102	< 85%	588	1	A
110893 NEEDHAM 115 110894 DOVER MA 115 1	115	101	< 85%	385	1	NONE
117327 DRUMROCK 115 117379 DRUMROCK TS 99.0 1	115	116	113	107	1	C

Overloaded Elements
2028 *Full* Scenario 1



Design Contingency

Scenario 1 POI
8.145 GW

» 5 POI

A. Canal 345 kV
B. Bourne 345 kV
C. Brayton Point 345 kV
D. Kent County 345 kV
E. Montville 345 kV

Potential 345kV Transmission Reinforcements Identified by ISONE

Overloaded Monitored Elements in Scenario 2 *Phased* & *Full* OSW Buildout (2024 & 2028)

Overloaded Transmission Elements (1 & 4)

- New Overloads (1 in 2024 & 4 in 2028)
- No Pre-existing Overloads Worse with OSW

2024

Monitored Facility	kV	2024 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 1	345	113	< 85%	596	2

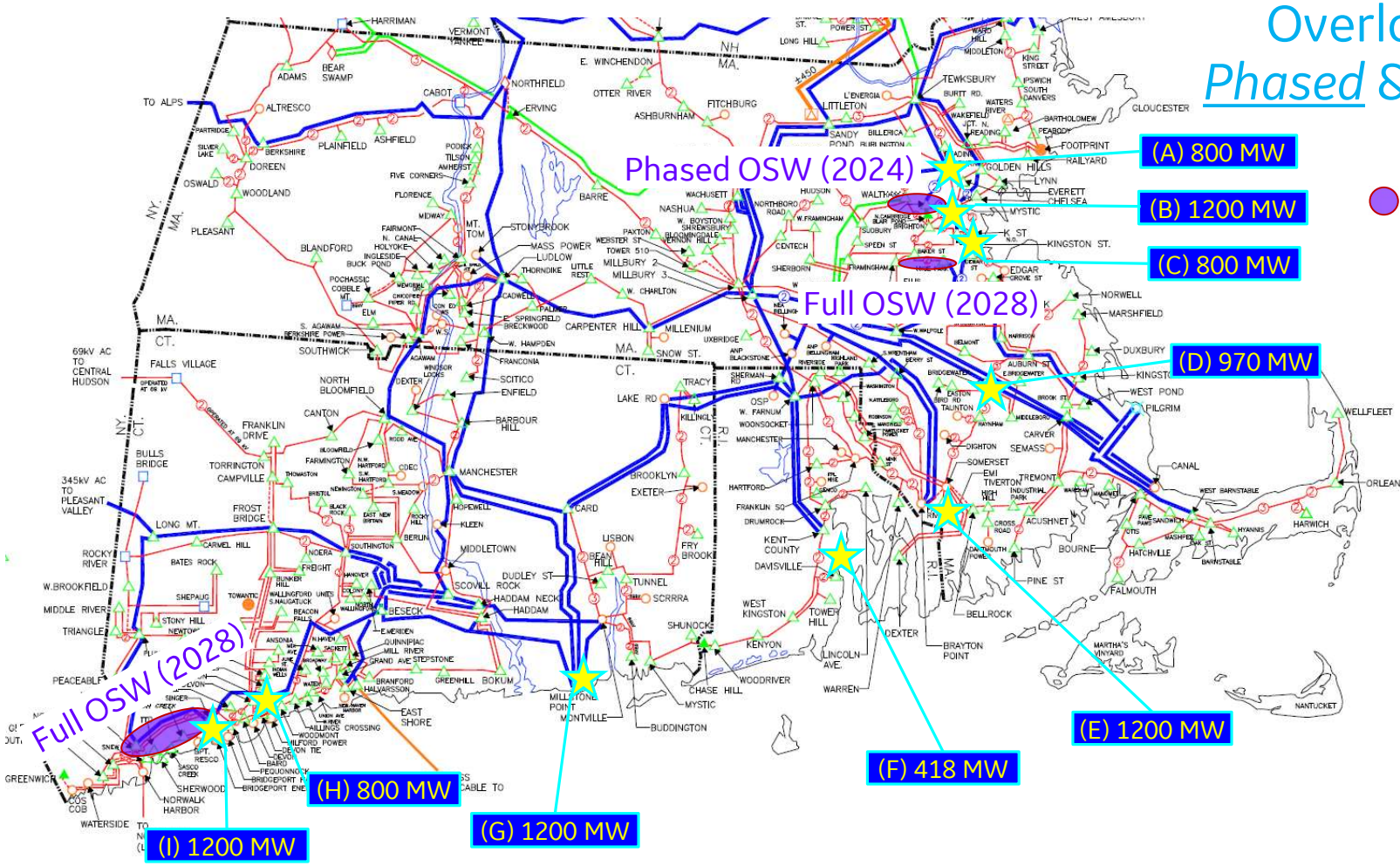
Overloaded Transmission Elements by kV:

- 345 kV Branches (1 in 2024 & 2 in 2028)
- 115 kV Branches (0 in 2024 & 2 in 2028)

2028

Monitored Facility	kV	2028 OSW Buildout AC Loading %	Scenario 2 Base Case AC Loading %	Rating (MVA)	Frequency
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	115	115	100	235	1
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	115	113	97	235	1
119441 NU_3921_UI 345 119480 NORWALK 345 1	345	107	< 85%	1133	3
119428 NU_3280_UI 345 119480 NORWALK 345 1	345	107	< 85%	1133	3

Overloaded Elements
Phased & *Full* Scenario 2



Design Contingency

Scenario 2 POI
8.588 GW

» 9 POI

A. Woburn 345 kV
B. Mystic 345 kV
C. K Street 345 kV
D. Bridgewater 345 kV
E. Brayton Point 345 kV
F. Kent County 345 kV
G. Millstone 345 kV
H. East Devon 345 kV
I. Singer 345 kV

N-1-1 Results

TARA Contingency Analysis

Overview of N-1-1 Methodology

Relevant Notes for TARA Analysis

N-1-1 analysis focuses on the next 3.6 GW offshore wind injection most immediately relevant

N-1-1 analysis for the full 8+ GW build out was beyond the scope of this analysis

NERC

» Allows Non-Consequential Load-Shedding for non-generator first contingency loss in N-1-1

NPCC

» For simplicity, Bulk Power System (BPS) Assumption for ISONE: 200kV+

» Actual ISONE BPS list contains many elements below 200kV

Overloaded Monitored Elements in Scenario 1

NPCC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
111133 CARVER 345 111193 CANAL 345 1	194.5	1221	3305	less than 85%	New Overloads Due to Scenario 1 OSW Buildout, NOT Overloaded in Base Case
110786 STOUGHTON 345 110790 K STREET 1 345 2	176.8	675	10474	100	
110786 STOUGHTON 345 110790 K STREET 1 345 1	174.6	675	4117	100	
110782 JORDAN ROAD 345 111193 CANAL 345 1	165.6	1446	1734	less than 85%	
111133 CARVER 345 115036 NGR_331_NST 345 1	144.1	1156	16	less than 85%	
110780 WEST WALPOLE 345 115008 NST_331_NGR 345 1	143.8	1156	16	less than 85%	
119168 HADDAM NECK 345 119180 MONTVILE_364 345 1	135.2	1884	3832	less than 85%	
111133 CARVER 345 115013 NGR_356_NST 345 1	130.3	1410	13	less than 85%	
119272 NE_398_NY 345 126294 PLTVLLEY 345 1	125.9	1382	7	less than 85%	
119194 MILLSTONE 345 119209 HADDAM 345 1	124.8	1884	104	less than 85%	
121408 NE_601_NY 138 129343 NRTHPT P 138 1	124.4	191	1	less than 85%	
121409 NE_602_NY 138 129343 NRTHPT P 138 2	124.0	191	1	less than 85%	
121410 NE_603_NY 138 129343 NRTHPT P 138 3	123.2	191	1	less than 85%	
113950 SANDY POND 345 113951 TEWKSBURY 345 1	121.8	1918	97	less than 85%	
119259 LONG MTN 345 119272 NE_398_NY 345 1	121.8	1428	6	less than 85%	
113264 MILLBURY 345 113265 WACHUSETT 345 1	118.9	1609	16	less than 85%	
110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	117.6	585	327	91	
119181 MONTVILE_371 345 119194 MILLSTONE 345 1	114.7	1884	18	less than 85%	
104191 NU_381_VEL 345 107040 VERNON VT 345 1	114.6	1491	41	88	
115008 NST_331_NGR 345 115036 NGR_331_NST 345 1	113.6	1466	12	less than 85%	
119129 KLEEN 345 119142 SCOVILLE RCK 345 1	112.8	1912	15	less than 85%	
104191 NU_381_VEL 345 104195 NU_381_NU 345 1	109.6	1626	6	less than 85%	
113265 WACHUSETT 345 113950 SANDY POND 345 1	109.2	1611	3	less than 85%	
104159 NU_326_NGR 345 113950 SANDY POND 345 1	108.0	1635	13	less than 85%	
119142 SCOVILLE RCK 345 119168 HADDAM NECK 345 1	107.3	1697	11	less than 85%	
123637 ESHORE 9X 345 123638 ESHORE TELEM 345 1	107.1	617	7	less than 85%	
119168 HADDAM NECK 345 119220 BESECK 345 1	107.1	1884	8	less than 85%	
119142 SCOVILLE RCK 345 119233 SOUTHINGTON 345 1	107.0	1884	8	less than 85%	
110781 HOLBROOK 345 115009 NGR_335_NST 345 1	105.9	1410	14	less than 85%	
110785 ANP BLACKSTN 345 115015 NGR_3361_NST 345 1	105.8	1685	16	less than 85%	
110780 WEST WALPOLE 345 110786 STOUGHTON 345 1	105.8	1649	4	less than 85%	
119077 MANCHESTER 345 119194 MILLSTONE 345 1	104.6	1797	15	less than 85%	
119402 NU_3165_UI 345 123626 SINGER 345 1	104.2	1074	9	87	
119415 NU_3619_UI 345 123626 SINGER 345 1	104.2	1074	9	87	
119209 HADDAM 345 119220 BESECK 345 1	103.9	1884	11	less than 85%	
123636 ESHORE 8X 345 123638 ESHORE TELEM 345 1	102.9	642	2	less than 85%	
110782 JORDAN ROAD 345 115011 NGR_342_NST 345 1	102.6	1855	4	less than 85%	
119389 EAST DEVON 345 119402 NU_3165_UI 345 1	101.7	1106	2	less than 85%	
119389 EAST DEVON 345 119415 NU_3619_UI 345 1	101.7	1106	2	less than 85%	
104151 LAWRENCE RD 345 104159 NU_326_NGR 345 1	101.1	1747	1	less than 85%	
110786 STOUGHTON 345 110788 HYDE PARK 345 1	100.6	676	1	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 2	196.0	675	82	115	Overloaded in Base Case, Worse with Scenario 1 OSW Buildout
110786 STOUGHTON 345 110790 K STREET 1 345 1	193.7	675	46	114	
119389 EAST DEVON 345 119415 NU_3619_UI 345 1	143.0	1106	1	121	
119389 EAST DEVON 345 119402 NU_3165_UI 345 1	143.0	1106	1	121	
119415 NU_3619_UI 345 123626 SINGER 345 1	142.2	1074	1	121	
119402 NU_3165_UI 345 123626 SINGER 345 1	142.2	1074	1	121	
119428 NU_3280_UI 345 119480 NORWALK 345 1	109.6	1133	1	103	
119441 NU_3921_UI 345 119480 NORWALK 345 1	109.2	1133	1	103	

NERC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
110814 BRIGHTON B 115 110855 WASH_TAP 511 115 1	174.2	150	7814	91	New Overloads Due to Scenario 1 OSW Buildout, NOT Overloaded in Base Case
110813 BRIGHTON A 115 110854 WASH_TAP 510 115 1	174.1	150	7806	91	
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	166.0	150	7851	100	
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	166.0	150	7848	100	
110786 STOUGHTON 345 110790 K STREET 1 345 2	160.4	675	588	100	
111133 CARVER 345 111193 CANAL 345 1	159.9	1221	63	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 1	158.3	675	164	99	
110888 BAKER ST A 115 110892 HYDE PARK B 115 1	142.4	235	59	98	
110782 JORDAN ROAD 345 111193 CANAL 345 1	141.9	1446	83	less than 85%	
110889 BAKER ST B 115 110891 HYDE PARK A 115 1	140.7	235	61	96	
110886 BAKER ST PS1 115 110888 BAKER ST A 115 1	137.5	205	952	89	
110887 BAKER ST PS2 115 110889 BAKER ST B 115 1	137.5	205	951	89	
104900 NORTH KEENE 115 104902 KEENE 115 1	121.9	135	2	less than 85%	
110835 HIGH ST 511 115 110837 K STREET 2 115 1	121.6	190	8	less than 85%	
110834 HIGH ST 510 115 110836 K STREET 1 115 1	121.1	190	8	less than 85%	
104935 CHESTNUT HIL 115 104946 VERNONROAD_T 115 1	120.0	234	1	less than 85%	
113950 SANDY POND 345 113951 TEWKSBURY 345 1	118.1	1918	4	less than 85%	
110830 KINGSTN ST W 115 110836 K STREET 1 115 1	117.7	190	5	less than 85%	
110830 KINGSTN ST W 115 110836 K STREET 1 115 2	117.7	190	5	less than 85%	
110893 NEEDHAM 115 110894 DOVER MA 115 1	116.9	385	185	100	
111149 HORSEPDTP108 115 111156 VALLEYNB 108 115 1	115.2	246	15	less than 85%	
104913 A152_T 115 104924 WESTPORT 115 1	113.5	234	1	less than 85%	
104924 WESTPORT 115 104935 CHESTNUT HIL 115 1	113.5	234	1	less than 85%	
104895 TUTTLE HILL 115 104900 NORTH KEENE 115 1	111.6	135	2	less than 85%	
104891 JACKMAN 115 104895 TUTTLE HILL 115 1	111.3	135	2	less than 85%	
110836 K STREET 1 115 110790 K STREET 1 345 1	110.4	750	1	less than 85%	
110837 K STREET 2 115 110790 K STREET 1 345 1	110.4	750	1	less than 85%	
119718 MONTVILLE 115 119181 MONTVILE_371 345 2	110.3	527	254	less than 85%	
104191 NU_381_VEL 345 104195 NU_381_NU 345 1	109.6	1626	1	less than 85%	
111142 VALLEYNB 113 115 111158 HORSEPDTP113 115 1	109.4	246	15	less than 85%	
111158 HORSEPDTP113 115 111217 BOURNE 115 1	109.4	246	15	less than 85%	
117330 JOHNSTON_171 115 117334 RISE 171_TAP 115 1	108.8	446	53	less than 85%	
104191 NU_381_VEL 345 107040 VERNON VT 345 1	108.1	1491	7	88	
111155 WAREHAM 108 115 111156 VALLEYNB 108 115 1	107.9	246	14	less than 85%	
119168 HADDAM NECK 345 119180 MONTVILE_364 345 1	107.5	1884	216	less than 85%	
111142 VALLEYNB 113 115 111152 WAREHAM 113 115 1	107.0	246	14	less than 85%	
111152 WAREHAM 113 115 111318 TREMONT 113 115 1	107.0	246	14	less than 85%	
113264 MILLBURY 345 113265 WACHUSETT 345 1	106.3	1609	1	less than 85%	
110770 W MEDWAY A 345 110794 W MEDWAY A 230 1	105.9	585	3	less than 85%	
117331 JOHNSTON_172 115 117360 RISE 172_TAP 115 1	103.6	446	3	less than 85%	
104159 NU_326_NGR 345 113950 SANDY POND 345 1	102.2	1635	1	less than 85%	
110814 BRIGHTON B 115 110815 N. CAMBRIDGE 115 1	102.2	231	2	less than 85%	
110785 ANP BLACKSTN 345 115015 NGR_3361_NST 345 1	101.0	1685	1	less than 85%	
110791 HYDE PARK 115 110788 HYDE PARK 345 1	100.3	600	1	less than 85%	
110855 WASH_TAP 511 115 110887 BAKER ST PS2 115 1	187.5	150	60	119	Overloaded in Base Case, Worse with Scenario 1 OSW Buildout
110854 WASH_TAP 510 115 110886 BAKER ST PS1 115 1	187.5	150	60	119	
110786 STOUGHTON 345 110790 K STREET 1 345 2	178.5	675	3	108	
110786 STOUGHTON 345 110790 K STREET 1 345 1	176.7	675	3	107	
110893 NEEDHAM 115 110894 DOVER MA 115 1	124.5	385	55	109	

Overloaded Monitored Elements in Scenario 2

NPCC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 1	174.1	596	22	less than 85%	New Overloads Due to Scenario 2 OSW Buildout, NOT Overloaded in Base Case
110758 N. CAMBRIDGE 345 110759 MYSTIC MA 345 2	147.6	705	10	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 2	120.7	675	1	less than 85%	
110786 STOUGHTON 345 110790 K STREET 1 345 1	120.1	675	1	less than 85%	
119428 NU_3280_UI 345 119480 NORWALK 345 1	111.1	1133	52	less than 85%	
119441 NU_3921_UI 345 119480 NORWALK 345 1	111.1	1133	52	less than 85%	
119181 MONTVILE_371 345 119194 MILLSTONE 345 1	106.7	1884	14	less than 85%	
114734 BRAYTN POINT 345 114900 BERRY STREET 345 1	104.4	1157	2	less than 85%	
119428 NU_3280_UI 345 119480 NORWALK 345 1	177.5	1133	1	102	Overloaded in Base Case, Worse with Scenario 2 OSW
119441 NU_3921_UI 345 119480 NORWALK 345 1	177.5	1133	1	102	

NERC Criteria

Overloaded Monitored Element	OSW Buildout AC %Loading	Rating (MVA)	Total N-1-1 Contingency Combinations	Base Case AC %Loading	New Overload or Makes Existing Overload Worse
115743 GRAND ARMY 115 115744 Z1_TAP 115 1	117.9	446	1	less than 85%	New Overloads Due to Scenario 2 OSW Buildout, NOT Overloaded in Base Case
115743 GRAND ARMY 115 115745 Y2_TAP 115 1	117.9	446	1	less than 85%	
115711 SOMERSET 115 115744 Z1_TAP 115 1	108.0	446	1	less than 85%	
115711 SOMERSET 115 115745 Y2_TAP 115 1	108.0	446	1	less than 85%	

Economic Production Cost Results

GE-MAPS Analysis

Much More Considered LMP Change in Scenario 2

Necessary Transmission Upgrades Assumption

What happens with no transmission upgrades in the Base Case with 3.1 GW OSW?

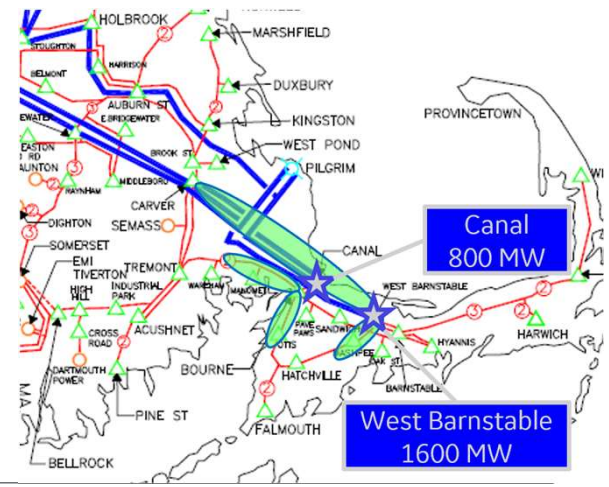
- Initial MAPS simulation showed 44% OSW curtailment at West Barnstable POI
- Curtailment is way too high and not a realistic starting point

Six transmission segments where upgrades necessary for reasonable starting point in **Base Case,** which are similar to the upgrades proposed in the QP828 Feasibility Study:

- Carver – West Barnstable 345 kV Line (399)
- West Barnstable – Mashpee 115 kV (137) and Otis – Bourne 115 kV Line (107)
- West Barnstable 345/115 kV Transformer
- Bourne – Horse Depot – Valley NB 115 kV Line (108)

Transmission Upgrades Assumed in Base Case

Powerflow					Ratings		
From Bus Number & Name		To Bus Number & Name		Ckt	Initial	Upgrade	Upgrade Description
111134	W BARNSTABLE345.00	111135	W BARNSTABLE115.00	1	604	1585	2nd Larger Parallel Transformer
111133	CARVER 345.00	111134	W BARNSTABLE345.00	1	1016	1585	Reconductor Line
111214	OTIS 115.00	111217	BOURNE 115.00	1	407	431	Reconductor Line
111135	W BARNSTABLE115.00	111215	MASHPEE 137 115.00	1	244	488	Parallel or Reconductor Line
111149	HORSEPDTP108115.00	111156	VALLEYNB 108115.00	1	246	291	Reconductor Line
111149	HORSEPDTP108115.00	111217	BOURNE 115.00	1	246	291	Reconductor Line



Transmission Upgrades for Reliability (NERC/NPCC)

Transmission upgrades modeled in respective offshore wind buildout scenarios required to mitigate N-1-1 transmission security violations according to NERC TPL Standards and NPCC Directory 1 Criteria

Scenario 1

- West Barnstable – K Street 345 kV
- West Barnstable – Mashpee – Hatchville – Fallmouth Tap 115 kV
- West Barnstable – Bourne – Canal – Valley – Wareham – Tremont 115 kV
- Johnson – Rise 115 kV

Scenario 2

- Mystic – North Cambridge – Woburn 345 kV
- Norwalk – Singer 345 kV

Annual Offshore Wind Generation Curtailment

Occurs when transmission constraints cause reduced generation output below full capability

Average ISONE Curtailment

- Base Case: 3% in 2024 & 2028*
- Scenario 1: 0.5% in 2024; 12.9% in 2028
- Scenario 2: 1.4% in 2024; 3.7% in 2028

		Average ISO-NE Curtailment			
Year	Technology Type	Base_S1	Base_S2	OSW_S1	OSW_S2
2024	Offshore	3.0%	3.0%	0.5%	1.4%
	Onshore	0.1%	0.1%	0.1%	0.1%
2028	Offshore	2.9%	3.0%	12.9%	3.7%
	Onshore	0.1%	0.1%	0.2%	0.8%

Max Offshore Wind Generation Curtailment:

- Base Case: 6% (West Barnstable 1600MW)
- In 2024, Scenario 1 & 2 have relatively low curtailment % of OSW POIs, all OSW curtailment is located in SEMA
- In 2028, Scenario 1 top OSW POI curtailment is significantly higher (Scenario 1: ***34%*** *vs* Scenario 2: ***14%***)
- In 2028, Scenario 1 showed curtailment > 5% in multiple areas: SEMA and CT; only SWCT for Scenario 2
- Scenario 2 OSW buildout does not result in any additional West Barnstable POI curtailment compared to Base Case

		Percent Curtailment by ISO-NE Offshore Site				
Simulation Year	POI	MAPS Area	Base_S1	Base_S2	OSW_S1	OSW_S2
2024	Bourne	SEMAA	0%	0%	0%	0%
	Brayton Point	SEMAA			0%	0%
	Canal	SEMAA	0%	0%	0%	0%
	Kent County	RIA	0%	0%	0%	0%
	Montville	CTA			0%	
	Mystic	BOSTONA				0%
	Singer Bridgeport	SWCTA				
	West Barnstable	SEMAA	6%	6%	1%	6%
2028	Bourne	SEMAA	0%	0%	0%	0%
	Brayton Point	SEMAA			0%	2%
	Bridgewater	SEMAA				1%
	Canal	SEMAA	0%	0%	34%	1%
	East Devon	SWCTA				6%
	K Street	BOSTONA				1%
	Kent County	RIA	0%	0%	1%	1%
	Millstone	CTA				3%
	Montville	CTA			13%	
	Mystic	BOSTONA				0%
	Singer Bridgeport	SWCTA				14%
	West Barnstable	SEMAA	6%	6%	6%	6%
	Woburn	BOSTONA				2%

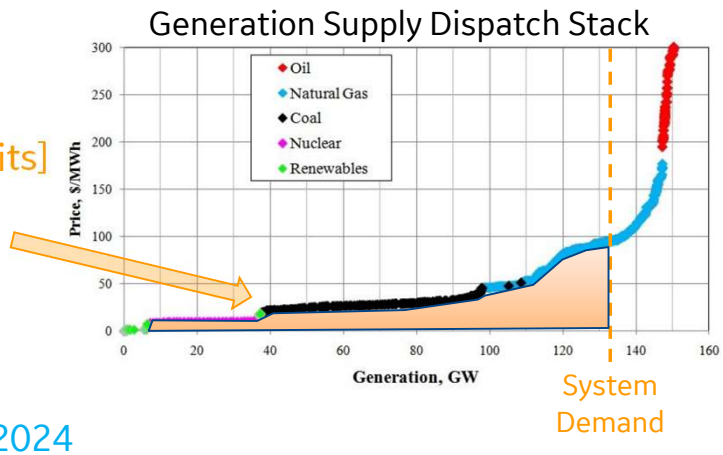
*2018 ISONE averaged 2% onshore wind curtailment

Annual ISONE Production Cost Savings

Electric energy production cost reflects variable operating costs

System Production Cost = Σ [Variable O&M Costs of Dispatched Units]

Area Under the Dispatch Curve



Production Cost Saving Comparison

- Production cost savings for both Scenario 1 & 2 are similar in 2024
- In 2028, Scenario 2 shows more production cost savings than Scenario 1 (difference of **$55M**)

ISO-NE Production Cost ($M)				
Year	Base_Case	Base_S2	OSW_S1	OSW_S2
2024	$1,774	$1,776	$1,489	$1,492
2028	$2,064	$2,062	$1,500	$1,443

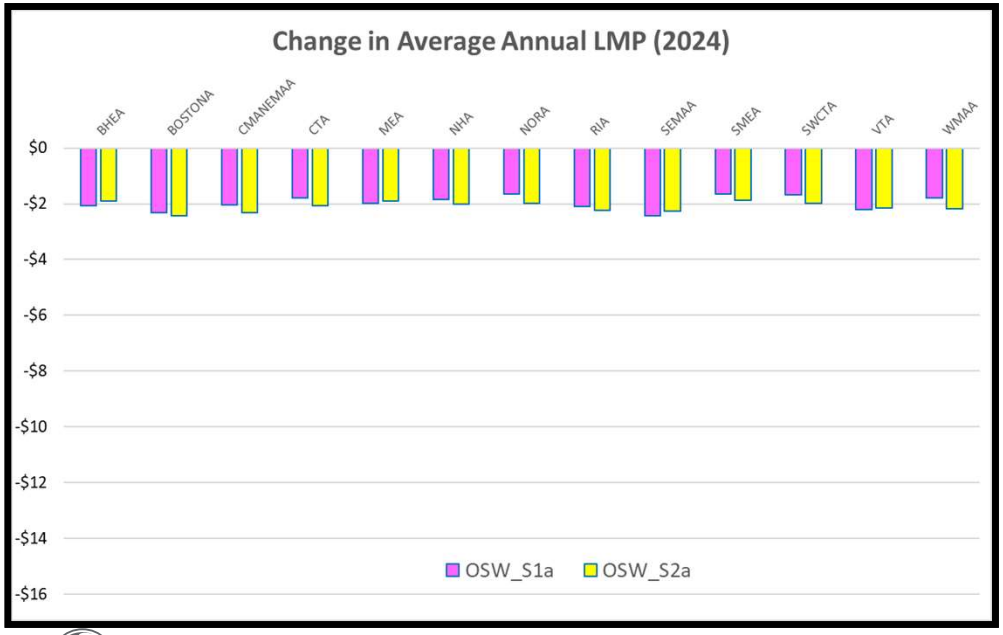
	Production Cost Savings ($M)	
Year	OSW_S1	OSW_S2
2024	$285	$284
2028	$564	$619

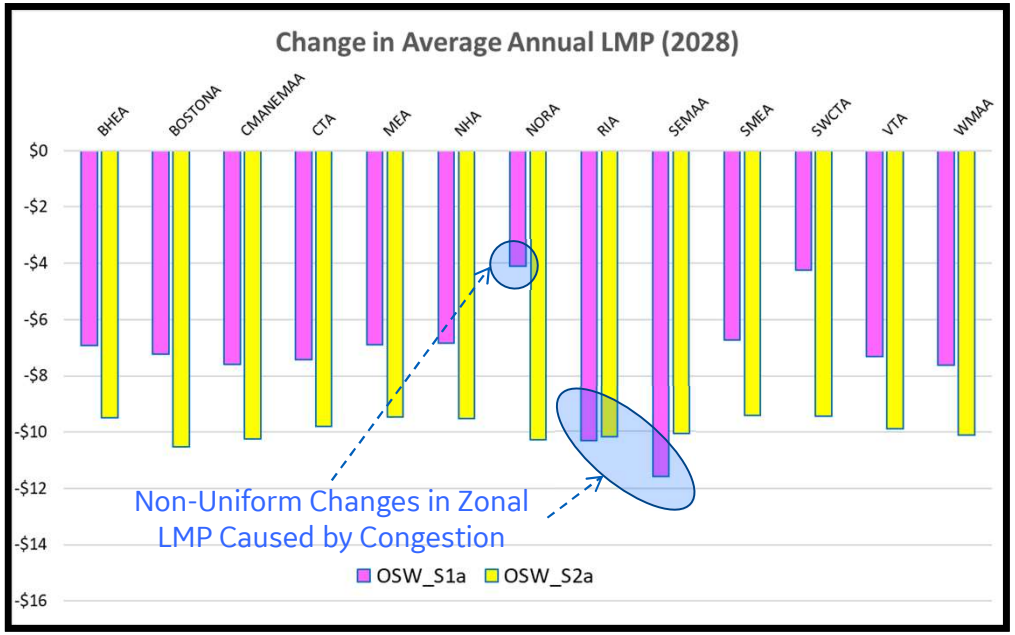
Annual ISONE Zonal LMP Change

Locational Marginal Price (LMP) = Marginal Cost of Electricity + Transmission Congestion Cost + Cost of Losses

In 2028, More Uniform Zonal LMP Decrease in Scenario 2 than Scenario 1 is an indication of:

- More efficient and cost-effective use of added cheap energy from OSW
- Less transmission congestion moving cheap OSW energy
- More load payment savings





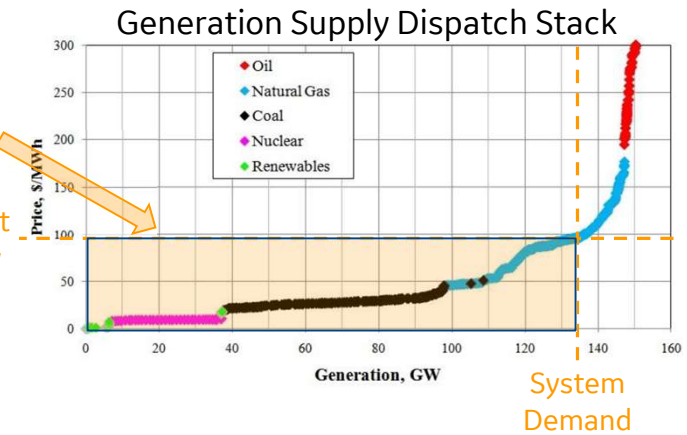
Load Payment Savings

Electricity Load Payment = Marginal Cost of Electricity ($/MWh) x System Demand (MWh)

Load payment is the amount the rate payers ultimately pay to serve the load in their area

Rectangle area bound by Marginal Price and Demand

Marginal Cost of Electricity



System Demand

Load Payment Comparison

- In 2024, similar annual load payment savings occur in Scenario 1 ($259M) vs. Scenario 2 ($281M), reflecting in a modest difference between the two OSW transmission scenarios (**$22M or 0.5%**).
- In 2028, the load payment savings between the two begin to diverge between Scenario 1 ($1,000M) vs. Scenario 2 ($1,306M) and the resulting annual difference is significant (**$306M or 5.2%**).

Annual ISO-NE Load Payment ($M)				
Year	Base_S1	Base_S2	OSW_S1	OSW_S2
2024	$4,815	$4,808	$4,557	$4,527
2028	$5,921	$5,897	$4,921	$4,591

	Load Payment Savings ($M)	
Year	OSW_S1	OSW_S2
2024	$259	$281
2028	$1,000	$1,306