GE Energy

Final Report:

New England Wind Integration Study

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ISO New England

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Foreword

This document was prepared by General Electric International, Inc. It is submitted to ISO New England, Inc. Technical and commercial questions and any correspondence concerning this document should be referred to:

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List of Acronyms and Abbreviations

ACE	Area Control Error
ATC	Available Transfer Capability
AWST	AWS Truepower
CC	Combined Cycle
CO2	Carbon Dioxide
CPS1	Control Performance Standard 1
CPS2	Control Performance Standard 2
CT	Combustion Turbine
DAM	Day-Ahead Energy Market
EIA	Energy Information Agency
ELCC	Effective Load Carrying Capability
EWITS	Eastern Wind Integration and Transmission Study
FERC	Federal Energy Regulatory Commission
FLHR	Full Load Heat Rate
GT	Gas Turbine
HVDC	High Voltage Direct Current
ICR	Installed Capacity Requirement
IPR	Intermittent Power Resources
IVGTF	Integration of Variable Generation Task Force
LAI	Levitan and Associates
LMP	Locational Marginal Price
LOLE	Loss of Load Expectation
LOLP	Loss of Load Probability
LTE	Long Time Emergency
MAE	Mean Absolute Error
MAPS	Multi Area Production Simulation
MARS	Multi Area Reliability Simulation
Net load	Time synchronous load minus wind generation output
NEWIS	New England Wind Integration Study

NEWRAM	New England Wind Resource Area Model
NLCD	National Land Cover Database
NOx	Nitrogen Oxides
NPCC	Northeast Power Coordinating Council
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PAC	Planning Advisory Committee
PSH	Pumped Storage Hydro
RSP	Regional System Plan
RTM	Real-Time Energy Market
RTO	Regional Transmission Organization
SIS	System Impact Study
S-o-A	State of the Art
SOx	Sulfur Oxides
TKE	Turbulent Kinetic Energy
TMNSR	Ten Minute Non-Spinning Reserve
TMOR	Thirty Minute Operating Reserve
TMSR	Ten Minute Spinning Reserve
TOR	Total Operating Reserve
TRC	Technical Review Committee
USGS	United States Geological Survey
UWIG	Utility Wind Integration Group

Executive Summary

Introduction

Overview of ISO-NE

ISO New England Inc. (ISO-NE) is the not-for-profit corporation that serves as the Regional Transmission Organization (RTO) and Independent System Operator (ISO) for New England. ISO-NE is responsible for the reliable operation of New England's power generation, demand response, and transmission system; administers the region's wholesale electricity markets; and manages the comprehensive planning of the regional power system. ISO-NE has the responsibility to protect the short-term reliability and plan for the long-term reliability of the Balancing Authority Area, a six-state region that includes approximately 6.5 million businesses and households.

Key Drivers of Wind Power

The large-scale use of wind power is becoming a norm in many parts of the world. The increasing use of wind power is due to the emissions-free electrical energy it can generate; the speed with which wind power plants can be constructed; the generation fuel source diversity it adds to the resource mix; the long-term fuel-cost-certainty it possesses; and, in some instances, the cost-competitiveness of modern utility-scale wind power. Emissions-free generation helps meet environmental goals, such as Renewable Portfolio Standards (RPS)[1] and greenhouse gas control. Once the permitting process is complete, some wind power plants can be constructed in as little as three to six months, which facilitates financing and quick responses to market signals. Wind power, with a fuel cost fixed at essentially zero, can contribute to fuel-cost certainty, and would reduce New England's dependence on natural gas. In New England, the economics of wind power are directly affected by the outlook for the price of natural gas; higher fuel prices generally spur development of alternative energy supplies while lower fuel prices generally slow such development. Wind power development also is directly affected by environmental

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[1] Each state in New England has adopted a renewable portfolio standard, except for Vermont, which has set renewable energy goals. RPSs set growing percentage-wise targets for electric energy supplied by retail suppliers to come from renewable energy sources. For a further description of New England related policies potentially affecting wind power see, for example, the ISO-NE Regional System Plan. RSP10 is available at: http://www.iso-ne.com/trans/rsp/index.html.

policy drivers such as restrictions on generator emissions or renewable energy generation targets.

While wind can provide low-priced zero-emissions energy, the variability of wind resources and the uncertainty with which the amount of power produced can be accurately forecasted poses challenges for the reliable operation and planning of the power system. Many favorable sites for wind development are remote from load centers. Development of these distant sites would likely require significant transmission development, which may not appear to be economical in comparison to conventional generation resources (at current prices) and could add complexity to the operations and planning of the system. The geographical diversity of wind power development throughout New England and its neighboring systems in New York and the eastern Canadian provinces would mitigate some of the adverse impacts of wind resource variability if the transmission infrastructure, operating procedures, and market signals were in place to absorb that variability across a larger system. Several Elective and Merchant Transmission Upgrades are in various stages of consideration to access these wind and other renewable resources.

Growth of Wind Power in New England

As of October 2010, approximately 270 megawatts (MW) of utility-scale wind generation are on line in the ISO New England system, of which approximately 240 MW are biddable assets. New England has approximately 3,200 MW of larger-scale wind projects in the ISO Generator Interconnection Queue, more than 1,000 MW of which represent offshore projects and more than 2,100 MW of which represent onshore projects.[2] The wind capacity numbers in the ISO queue are based on nameplate ratings. Figure 0–1 shows a map of planned and active wind projects in New England. As an upper bound of all potential wind resources—and not including the feasibility of siting potential wind projects—New England holds the theoretical potential for developing more than 215 gigawatts (GW) of onshore and offshore wind generation.[3]

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[2] The 3,200 MW of wind in the queue is as of October 1, 2010, and includes projects in the affected non-FERC queue.

[3] 2009 Northeast Coordinated System Plan (May 24, 2010); http://iso-ne.com/committees/comm_wkgrps/othr/ipsac/ncsp/index.html.

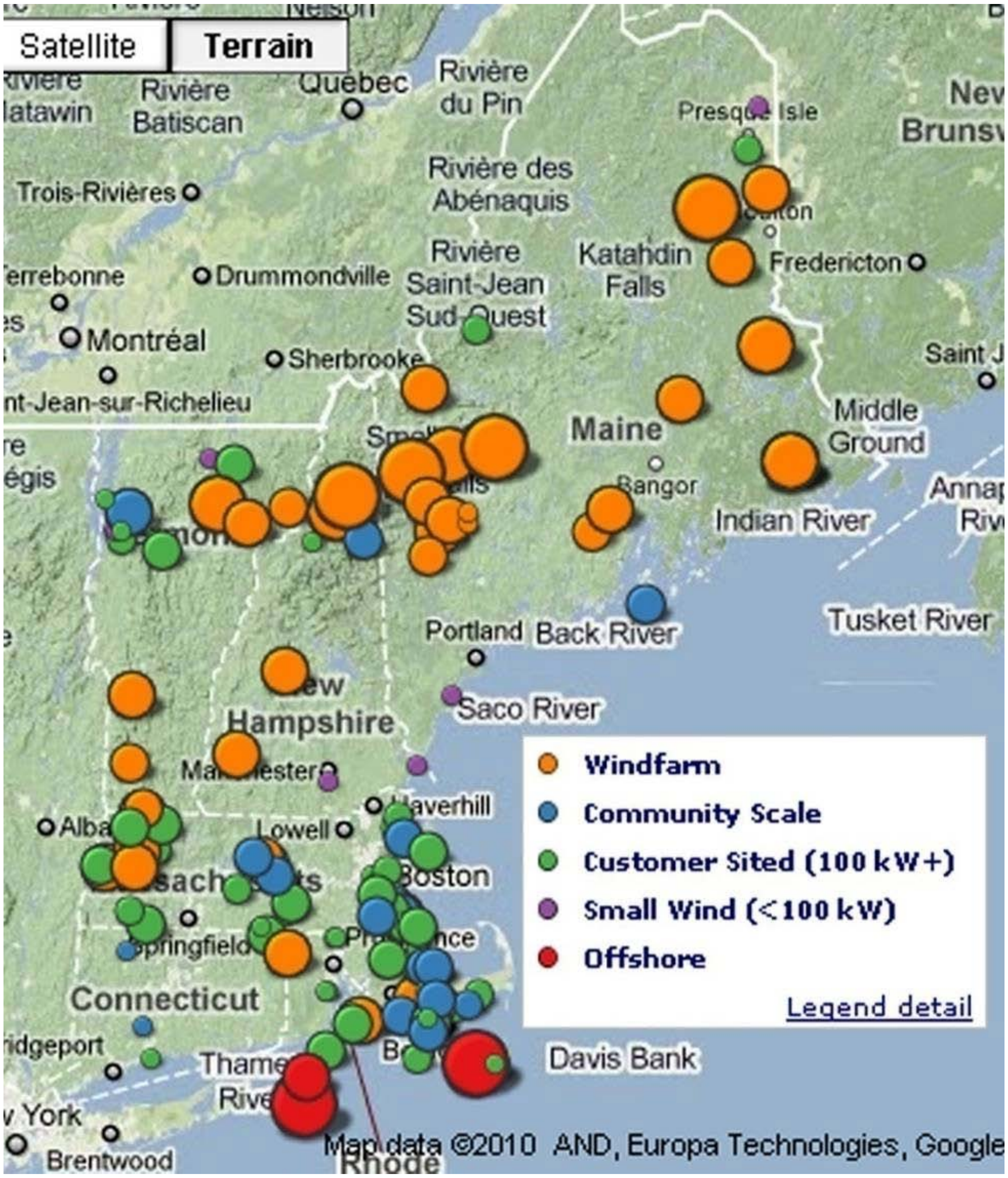

Figure 0–1 Planned and active wind projects in New England, 2010. Source: Sustainable Energy Advantage

The Governor's Economic Study

In 2009, the ISO completed the Scenario Analysis of Renewable Resource Development (the "Governors' Economic Study") – a comprehensive analysis for the integration of renewable resources over a long-term horizon, performed at the request of the Governors of the six New

England states.[4] The Governors' Economic Study identified economic and environmental impacts for a set of scenario analyses that assumed the development of renewable resources in New England. The study also identified the potential for significant wind power development in the New England states, the effective means to integrate this wind power development into the grid, and related preliminary transmission cost estimates. It did not evaluate operational impacts. Certain scenarios analyzed in the study indicated that, through development in the Northeast, New England and its neighbors could effectively meet the renewable energy goals of the region. Other scenarios showed that the region could be a net exporter of renewable energy.

The Governors' Economic Study ultimately informed the New England Governors' Renewable Energy Blueprint (the "Blueprint"), adopted last year by the six New England state governors.[5] The Blueprint sets forth policy objectives for the development of renewable resources in the Northeast that could ultimately lead to substantial penetration of wind power in New England.

Operational Effects of Large-scale Wind power

Large-scale wind integration adds complexity to power system operations by introducing a potentially large quantity of variable-output resources and the new challenge of forecasting wind power in addition to load.

The power system is designed and operated in a manner to accommodate a given level of uncertainty and variability that comes from the variability of load and the uncertainty associated with the load forecast as well as the uncertainty associated with the outage of different components of the system, such as generation or transmission. Due to a long familiarity with load patterns and the slowly changing nature of those patterns, the variability of the load is quite regular and well understood. The result is that the power system has been planned to ensure that different types of resources are available to respond to the variability of the load (e.g., baseload, intermediate, and fast-start resources have come into service) and the uncertainty associated with the load forecast is generally very small. The uncertainty associated with equipment outages is of a more discrete and "event" type nature that can be handled in a

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[4] The Governor's Economic Study is available on the ISO's website at: http://www.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/reports/index.html.
The Governor's Economic Study was conducted pursuant to the Regional System Planning Process established in Attachment K of the ISO OATT.

[5] See Blueprint Materials, available at: http://www.nescoe.com/Blueprint.html.

relatively deterministic fashion. This is the basis of contingency analysis where lists of credible contingencies are evaluated on a frequent periodic basis for their effects on power systems operations.

The combination of wind power's variability and the uncertainty of forecasting wind power make it fundamentally different from analyzing and operating other resources on the system. The weather patterns that drive the generation characteristics for wind power vary across many timescales and are loosely correlated with load. For example, ISO-NE experiences its peak loads during the summer months, while, as observed in this study, wind generation produces more energy during the winter months than in the summer. The uncertainty associated with wind generation is very different from the uncertainty associated with typical dispatchable resources. In general, uncertainty of energy supply from dispatchable conventional generation is due to forced unit outages due to equipment failures or other discrete events. Uncertainty in wind generation is more like uncertainty due to load. The amount of wind generation expected for the next day is forecasted in advance (just as load is forecasted in advance), and the amount of wind generation that actually occurs may be different from the forecasted amount, within the accuracy range of the forecast. In contrast, however, to forecasting of day-ahead load where typical average error is on the order of 1% to 3% Mean Absolute Error (MAE); the accuracy of state-of-the-art day-ahead wind forecasts is in the range of 15% to 20% MAE of installed wind rating. For small amounts of installed wind, load uncertainty dominates, but at higher penetrations of wind, forecast uncertainty becomes very important. In order to plan for the reliable operation of the power system, it is important to study how this combination of variability and associated uncertainty will affect power system operations far enough ahead of time for the effects to be quantified and any required mitigation measures to be put into service.

The loose correlation of wind and load requires the use of a new metric, "net load," to study the impact of large-scale wind generation where the fleet of dispatchable resources is used to balance the time-synchronous variability and uncertainty of the load minus the output of the wind generation. When managing the power system, the output of variable resources such as wind power can be directly subtracted from the amount of load to be served, the dispatchable resources on the system are then used to serve this remaining (i.e., "net") load in order to maintain the power system balance. The net load is then the true variability that must be managed with dispatchable resources and therefore it is the net load that must be studied when determining operational effects.

NEWIS Tasks and Analytical Approach

Anticipating the possible penetration of large-scale wind power in New England, ISO-NE also commissioned this comprehensive wind integration study in 2009 – the New England Wind Integration Study (the NEWIS) – to assess the operational effects of large-scale wind penetration in New England using statistical and simulation analysis of historical data.[6], [7] By focusing on the operational effects of large-scale wind integration, the NEWIS complements and builds on the results of the Governors' Economic Study.

The goals of the NEWIS were to determine the operational, planning and market impacts of integrating substantial wind generation resources for the New England Balancing Authority Area, with due consideration to the neighboring areas, as well as, the measures that may be available to ISO-NE for mitigating any negative impacts while enabling the integration of wind. The NEWIS also sets forth recommendations for implementing these measures. Additionally, the NEWIS identifies the potential operating conditions created or exacerbated by the variability and unpredictability of wind generation resources, and recommends potential corrective activities, recognizing the unique characteristics of the tightly integrated bulk power system in New England and the characteristic of wind generation resources. Consistent with the Governors' Economic Study, the NEWIS examines various scenarios of increasing wind power penetration up to approximately 12 GW of nameplate wind power.

In order to accomplish its goals, the NEWIS captures the unique characteristics of New England's bulk electrical system including load and ramping profiles, geography, system topology, supply and demand-side resource characteristics, and wind profiles and their unique impacts on system operations and planning with increasing wind power penetration. To facilitate the work of the NEWIS, it is broken into five tasks:

Wind Integration Study Survey - involved a review of the experience gained and lessons learned from several previous domestic and international wind integration studies on bulk electric power systems.

Technical Requirements for Interconnection - included the development of specific recommendations for technical requirements for wind generating resources; also investigated and recommended wind power forecasting tools that would be required for system operations as wind penetration increases. This task was completed in fall 2009, with recommendations to

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[6] See NEWIS Materials, New England Wind Integration Study (NEWIS) Wind Scenario and Transmission Overlays, available at: http://www.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/mtrls/2010/jan212010/newis.pdf.

[7] The core project team included GE Energy Applications and Systems Engineering, EnerNex, and AWS Truepower. Many members of this team have extensive experience and have been among the pioneers of wind integration analysis.

ISO-NE detailed in a report titled "Technical Requirements for Wind Generation Interconnection and Integration"[8].

Mesoscale Wind Forecasting and Wind Plant Models - included development of an accurate and flexible mesoscale hindcasting model for the New England and Maritimes wind resource area (including offshore wind resources) that provides user-specified wind plant output profile data. This tool allows reuse of the mesoscale modeling data for further ISO-NE studies.

Scenario Development and Analysis - developed base case and wind generation scenarios, in consultation with ISO-NE and stakeholders, that included potential and probable scenarios for wind power development up to 24% annual wind energy penetration. This task also included statistical analysis to evaluate the impact of incremental wind generation on the operation of New England's bulk electric power system, focusing on the effects of variability and uncertainty.

Scenario Simulation and Analysis - included production simulations to evaluate the hourly operation of the various scenarios and penetration levels for three calendar years, as well as rigorous reliability calculations using Loss of Load Expectation (LOLE) methods to evaluate the capacity value of the wind generation.

In order to be clear about the interpretation of the methods used, results obtained, and any recommendations provided, it is important to recognize what the NEWIS is and what it is not. The NEWIS is neither a transmission planning study nor a blueprint for wind power development in New England, and large-scale wind power development might or might not occur in the region. The NEWIS takes a snapshot of a hypothetical future year where low, moderate, and large wind power penetrations are assumed. Feedback dynamics in markets, such as the impact of overall reduced fuel use and the changes in fuel use patterns on fuel supply and cost, were not analyzed or accounted for. It is not a goal of ISO-NE to increase the amount of any particular resource; instead the ISO's goal is to provide mechanisms to ensure that it can meet its responsibilities (stated above) for operating the system reliably, managing transparent and competitive power system markets, and planning for the future needs of the

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[8] See NEWIS Technical Report, available at:
http://www.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2009/newis_report.pdf.
ISO-NE presented the recommendations of the NEWIS Technical Report to New England stakeholders at the November 18, 2009 meeting of the Planning Advisory Committee ("PAC"). *These recommendations will be subject to the applicable stakeholder processes prior to implementation.*

system, while providing a means to facilitate innovation and the fulfillment of New England's policy objectives. In this context, the NEWIS is meant to investigate whether there are any insurmountable operational challenges that would impede ISO-NE's ability to accept large amounts of wind generation.

A fundamental assumption in the NEWIS is that the transmission required to integrate the hypothesized wind generation into the bulk power system would be available and that the wind power resources would interconnect into those bulk transmission facilities. The NEWIS is a system-wide transportation study and, as such, does not account for local issues. For example, even with the limited wind generation that currently exists on the ISO-NE system, there are some instances where local transmission constraints result in curtailment of wind facilities due to the typical development pattern of wind generation facilities in New England and their interconnection under the minimum interconnection standards process. Implementing the recommendations developed as a result of the NEWIS will not solve these issues, unless the aforementioned sizable transmission expansions were to be built and the wind generation facilities were to connect directly into those expansions.

Another important assumption is that the available portfolio of non-wind generation in New England and neighboring systems was held constant across all alternatives considered. Neither attrition nor addition of new non-wind generation was considered as modifications to the base case.

Furthermore, detailed and extensive engineering analysis regarding stability and voltage limits would be required in order to determine the viability of the hypothesized transmission expansions, which in themselves may require substantial effort to site and build. It is also important to note that implementing the recommendations developed during the second task of the NEWIS (e.g., wind power specific grid support functions, wind power forecasting, windplant modeling, and communications and control) is essential for the reliable integration of large-scale wind power into the New England power system.

Finally, in addition to the significant observations mentioned above, changes may be required to systems and procedures within the ISO organization that are yet to be determined. These changes would require additional analysis for increasing levels of wind penetration and for issues identified within New England, or beyond, as system operators gain experience with wind energy. The development, implementation, and operating costs associated with these changes are not accounted for in this study.

Study Scenarios

All of the NEWIS wind scenarios are set to represent approximately the 2020 timeframe. In addition to the base case assumptions, there are five main categories of wind build-out scenarios representing successively greater penetrations of wind. The scenarios are categorized by the aggregate installed nameplate capacity of wind power and the simulated wind fleet's contribution to the region's forecasted annual energy demand. Values used for wind energy generated by each scenario are averages of the three years simulated via mesoscale modeling. Values of annual energy demand for the region and individual states are also averages for the three extrapolated load years used in the simulations and individual load supplied by energy efficiencies that has been bid into the Forward Capacity Market.

These categories of wind build-out scenarios include:

- Partial Queue Build-out
    - Represents 1.14 GW of installed wind capacity
    - Approximately 2.5% of the forecasted annual energy demand
- Full Queue Build-out
    - Represents 4.17 GW of installed wind capacity
    - Approximately 9% of the forecasted annual energy demand
- Medium wind penetration
    - Represents between 6.13 GW and 7.25 GW of installed wind capacity
    - Approximately 14% of the forecasted annual energy demand
- High wind penetration
    - Represents between 8.29 GW and 10.24 GW of installed wind capacity
    - Approximately 20% of the forecasted annual energy demand
- Extra-high wind penetration
    - Represents between 9.7 GW (for offshore) or 12 GW (for onshore) of installed wind capacity
    - Approximately 24% of the forecasted annual energy demand

Of the five categories, the Partial Queue and Full Queue build-outs are comprised of projects that were in the ISO Generator Interconnection Queue as of April 17, 2009, and the queue lists the proposed point of interconnection for each project. All of the build-outs with greater wind penetration consist of wind plants strategically chosen and added to the Full Queue site portfolio, until either the desired aggregate nameplate capacity or the desired energy contribution of the resulting wind fleet was satisfied. A range of wind plant scenarios was developed to represent what the New England system might look like with varying levels of wind penetration, and to represent different spatial patterns of wind development that could occur, including wind development in the Canadian Maritime Provinces. The objective of scenario development was to enable a detailed evaluation of the operational impacts of incremental wind generation variability and uncertainty on New England’s bulk electric power system, including the incremental impact contributed by the spatial diversity of wind plants. The NEWIS was not intended to identify real or preferred wind integration scenarios.

In order to represent the impacts of wind portfolio diversity, five layout alternatives were developed for the medium and high wind penetration build-out scenarios, i.e., the 14% energy and 20% energy scenarios, based on sites with the best (highest) capacity factors. Two of these layout alternatives were also used for the extra-high wind penetration build-out scenario. A description of the five layout alternatives developed for each energy target follows:

1. Best Sites Onshore – This alternative includes the onshore sites with the highest capacity factor needed to satisfy the desired regional energy or installed capacity component provided by wind power. This alternative’s wind fleet is comprised predominantly of wind plants in northern New England and therefore it exhibits low geographic diversity.

2. Best Sites Offshore – This alternative includes the offshore sites with the highest capacity factor needed to satisfy the desired regional energy or installed capacity component provided by wind power. This alternative features the highest overall capacity factor of each energy/capacity scenario set, but also a low geographic diversity. However, the steadier offshore wind resource features a higher correlation with load than onshore-based alternatives.

3. Balance Case – This alternative is a hybrid of the best onshore and offshore sites, and as such exhibits a high geographic diversity, including a good diversity by state. The offshore component of the wind fleet is divided equally between the states of Massachusetts, Rhode Island, and Maine (this is also the only alternative that includes offshore sites located in Maine).

4. Best Sites by State – This alternative likely represents the most spatially diverse native wind fleet, and is comprised of wind plants exhibiting the highest capacity factor within each state to meet that state’s contribution of the desired energy goal. For example, in the 20% energy scenario, each state’s wind fleet was built out in an attempt to meet 20% of the state’s projected annual energy demand so that the overall target of 20% of projected annual energy for New England was satisfied. This alternative enables the investigation of the effects of high diversity and wind power development close to New England’s load centers. It should be noted that since the Full Queue contained a disproportionately high capacity of wind projects located in

Maine, the aggregate energy produced from these plants contributes approximately 58% of this state's forecasted annual energy demand. This meant that the energy contribution of each of the other states was adjusted (percentage-wise) so that the regional wind fleet would produce the overall desired contribution to the forecasted regional energy demand.

5. Best Sites Maritimes – In addition to the Full Queue sites located within New England, this alternative is made up of extra-regional wind plants in the Canadian Maritime Provinces sufficient to satisfy the desired New England region's wind energy or installed capacity. No considerations were made regarding transmission upgrades required to deliver the hypothetical wind power to New England. Wind resources in the Maritimes exhibit a high geographic diversity and an overall capacity factor approaching that of New England's offshore resource. Considering the wind plants in the Full Queue, this alternative features the greatest geographic diversity. Also, given the longitudinal distance of the Maritimes from much of New England, the effects of integrating wind in the presence of time zone shifts could be highlighted.

Wind Data

AWS Truepower (AWST) developed a mesoscale wind model for the NEWIS study area, referred to as the New England Wind Resource Area Model (NEWRAM). The development of NEWRAM is based on the work that AWST conducted as part of the Eastern Wind Integration and Transmission Study (EWITS), for which AWST developed the wind resource and wind power output data. The resulting superset of simulated wind resource data is referred to as NREL's Eastern Wind Dataset and represents approximately 790 GW of potential future wind plant sites within the EWITS study area, and includes almost 39 GW of potential wind resource within the New England region. For the NEWIS, the New England portion of this wind dataset was expanded to include wind resources in the Canadian Maritimes and additional siting screens and validation analyses were applied. This NEWRAM dataset, which includes wind plant power output profiles as well as day-ahead wind forecasts for the calendar years of 2004, 2005, and 2006, provided the raw material necessary to build the various wind scenarios for the NEWIS.

Load Data

The load data used in the hourly production cost simulation analysis portion of the NEWIS comes from the ISO-NE pricing nodes (aka. p-nodes). P-nodes represent locations on the transmission system where generators inject power into the system or where loads withdraw power from the system. For the NEWIS, the load data from p-nodes has been aggregated into the respective Regional System Plan subareas. Historical data was extracted for years 2004, 2005, and 2006.

One-minute average total ISO New England load data was derived from the Plant Information (PI) data historian, which extracts data from the Energy Management System used for power system control.

Transmission Expansions

The NEWIS used a base-case transmission configuration for the 2019 ISO-NE system, as well as three transmission overlays developed as part of the previously described 2009 Governors' Study:

- 2019 ISO-NE System ("existing") – used for base case.[9]
- Governors' 2 GW Overlay – used as developed for Governor's Study.
- Governors' 4 GW Overlay/1,500 MW New Brunswick Interchange – An additional 345 kV line taken from the Governors' 8 GW Overlay was included for Southeastern Massachusetts in this overlay.
- Governors' 8 GW Overlay/1,500 MW New Brunswick Interchange

Due to scope constraints, only thermal limits were developed, investigated, and utilized for the NEWIS study. Voltage and stability limits would very likely reduce assumed transfer capability so the transfer capabilities of the hypothesized transmission expansion assumed in the study should be considered an upper bound.

Analytical Methods

The primary objective of this study was to identify and quantify system performance or operational problems with respect to load following, regulation, operating reserves, operation during low-load periods, etc. Three primary analytical methods were used to meet this objective: statistical analysis, hourly production simulation analysis, and reliability analysis. While the NEWIS tested the feasibility of wind integration under hypothetical future scenario analyses developed for the study, real world operating and system performance conditions can vary significantly from these types of hypothesized scenarios.

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[9] The base-case system for 2019 assumes completion of transmission projects in the 2009 RSP.

Statistical analysis was used to quantify variability due to system load, as well as wind generation over multiple time frames (annual, seasonal, daily, hourly, and 10-minute). The power grid already has significant variability due to periodic and random changes to system load. Wind generation adds to that variability, and increases what must be accommodated by load following and regulation with other generation resources. The statistical analysis quantified the grid variability due to load alone over several time scales, as well as the changes in grid variability due to wind generation for each scenario. The statistical analysis also characterized the forecast errors for wind generation.

Production simulation analysis with General Electric's Multi-Area Production Simulation software (GE MAPS) was used to evaluate hour-by-hour grid operation of each scenario for three years with different wind and load profiles. The production simulation results quantified numerous impacts on grid operation including the primary targets of investigation:

- Amount of maneuverable generation on-line during a given hour, including its available ramp-up and ramp-down capability to deal with grid variability due to load and wind
- Effects of day-ahead wind forecast alternatives in unit commitment
- Changes in dispatch of conventional generation resources due to the addition of new renewable generation
- Changes in transmission path loadings

Other measures of system performance were also quantified, including:

- Changes in emissions (NOx, SOx, CO2) due to renewable generation
- Changes in energy costs and revenues associated with grid operation, and changes in net cost of energy
- Changes in use and economic value of energy storage resources

Reliability analysis involved loss of load expectation (LOLE) calculations for ISO-NE system using General Electric's Multi-Area Reliability Simulation program (GE MARS). The analysis quantified the impact of wind generation on overall reliability measures, as well as the capacity values of the wind resources. ISO-NE's current method of determining the capacity value of wind plants was also compared with the LOLE/ELCC method. [10]

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[10] Loss of load expectation (LOLE) is the expected number of hours or days that the load will not be met over a defined time period. Effective Load Carrying Capability (ELCC) is a data driven metric for capacity value, and represents the amount of additional load that can be served by the addition of a generator while maintaining the existing level of reliability.

Impacts on system-level operating reserves were also analyzed using a variety of techniques including statistics and production simulation. This analysis quantified the effects of variability and uncertainty, and related that information to the system's increased need for operating reserves to maintain reliability and security.

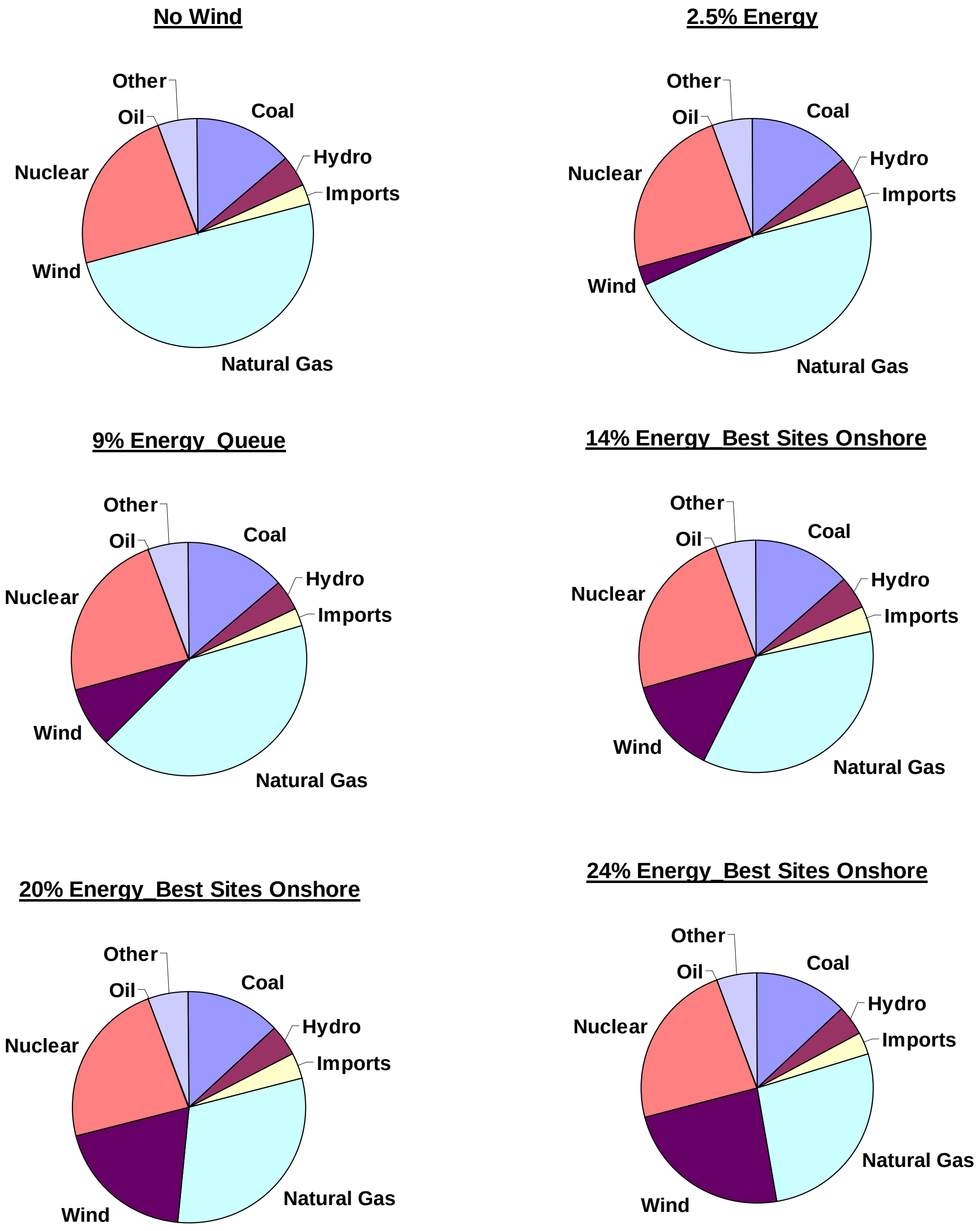
The results from these analytical methods complemented each other, and provided a basis for developing observations, conclusions, and recommendations with respect to the successful integration of wind generation into the ISO-NE power grid.

Key Findings and Recommendations

The study results show that New England could potentially integrate wind resources to meet up to 24% of the region’s total annual electric energy needs in 2020 if the system includes transmission upgrades comparable to the configurations identified in the Governors’ Study. It is important to note that this study assumes (1) the continued availability of existing supply-side and demand-side resources as cleared through the second FCA (in other words, no significant retirements relative to the capacity cleared through the second FCA), (2) the retention of the additional resources cleared in the second Forward Capacity Auction, and (3) increases in regulation and operating reserves as recommended in this study.

Figure 0–2 shows the annual energy from the ISO-NE generation fleet with increasing levels of wind generation for the NEWIS study of the horizon year 2020. The pie charts are for the best sites onshore layout, but since energy targets are the same for all layout alternatives within each scenario, the results presented in the pie charts are very similar across the range of layout alternatives within each scenario.

The existing ISO-NE generation fleet is dominated by natural-gas-fired resources, which are potentially very flexible in terms of ramping and maneuvering. As shown in the upper left pie chart of Figure 0–2 natural gas resources provide about 50% of total annual electric energy in New England assuming no wind generation on the system. Wind generation would primarily displace natural-gas-fired generation since gas-fired generation is most often on the margin in the ISO-NE market. The pie charts show that as the penetration of wind generation increases, energy from natural gas resources is reduced while energy from other resources remains relatively constant. At a 24% wind energy penetration, natural gas resources would still be called upon to provide more than 25% of the total annual energy (lower right pie chart). In effect, a 24% wind energy scenario would likely result in wind and natural-gas-fired generation providing approximately the same amount of energy to the system, which would represent a major shift in the fuel mix for the region. It is unclear, given the large decrease in energy market revenues for natural-gas-fired resources, whether these units would be viable and therefore continue to be available to supply the system needs under this scenario.



No Wind

2.5% Energy

9% Energy_Queue

14% Energy_Best Sites Onshore

20% Energy_Best Sites Onshore

24% Energy_Best Sites Onshore

Figure 0–2 Annual Energy from ISO-NE Generation Fleet with Increasing Wind Energy Penetration.

The remainder of this chapter is organized as follows: The section on Statistical Analysis through the section covering Capacity Value of Wind Generation summarize key analytical results related to statistical characterization of the scenarios, regulation and operating reserves, impacts on hourly operations, and capacity value of wind generation. The High-Level Comparison of Scenario Layouts section presents a high-level comparison of the study scenarios. The Recommended Changes to ISO-NE Operating Rules and Practices section presents recommended changes to ISO-NE operating rules and practices related to the following issues:

- Capacity Value
- Regulation
- Reserves
- Wind Forecasting
- Maintaining System Flexibility
- Wind Generation and Dispatch
- Saving and Analyzing Operating Data

The Other Observations from Study Results section summarizes other significant observations from the study results, including:

- Flexible Generation
- Energy Storage
- Dynamic Scheduling
- Load and Wind Forecasting with Distributed Wind Generation

The Technical Requirements for Interconnection of Wind Generation section relates recommendations and observations in this report back to the technical requirements for interconnection of wind plants in the previously published Task 2 report. The Future Work section includes recommendations for future work.

Statistical Analysis

The observations and conclusions here are made on the basis of three years of synthesized meteorological and wind production data corresponding to calendar years 2004, 2005, and 2006. Historical load data for those same calendar years were scaled up to account for anticipated load growth through year 2020.

The wind generation scenarios defined for this study show that the winter season in New England is where the highest wind energy production can be expected. As is the case in many other parts of the United States, the higher load season of summer is the “off-season” for wind generation.

While New England may benefit from an increase in electric energy provided by wind generation primarily during the winter period, the region will still need to have adequate capacity to serve summer peak demand. Given current operating practices and market structures, the potential displacement of electric energy provided by existing resources raises some concern for maintaining adequate capacity (essential for resource adequacy) and a flexible generation fleet (essential to balance the variability of wind generation).

The capacity factors for all scenarios follow the same general trend. Seasonal capacity factors above 45% in winter are observed for several of the scenarios. In summer, capacity factors drop to less than 30%, except for those scenarios that contain a significant share of offshore wind resources.

Based on averages over the entire dataset, seasonal daily patterns in both winter and summer exhibit some diurnal (daily) behavior. Winter wind production shows two daily maxima, one in the early morning after sunrise, and the other in late afternoon to early evening. Summer patterns contain a drop during the nighttime hours prior to sunrise, then an increase in production through the morning hours. It is enticing to think that such patterns could assist operationally with morning load pickup and peak energy demand, but the patterns described here are averages of many days. The likelihood of any specific day ascribing to the long-term average pattern is small.

The net load average patterns by season reveal only subtle changes from the average load shape. No significant operational issues can be detected from these average patterns. At the extremes, the minimum hourly net load over the data set is influenced substantially. In one of the 20% energy scenario layouts, the minimum net load drops from just about 10 GW for load alone to just over 3 GW. Impacts of these low net load periods were assessed with the production simulation analysis.

The day-ahead wind power forecasts developed for each scenario show an overall forecast accuracy of 15% to 20% Mean Absolute Error (MAE). This is consistent with what is considered the state of the commercial art. These forecast errors represent the major source of uncertainty attributable to wind generation. The impacts of forecast errors on hourly operations were evaluated in the production simulation analysis.

Shorter-term wind power forecasts are also valuable for system operations. This study addressed the use of persistence forecasts over the hour-ahead and ten-minute-ahead time periods. A persistence forecast assumes that future generation output will be the same as current conditions. For slowly changing conditions, short-term persistence forecasts are currently about as accurate statistically as those that are skill-based, but this relationship breaks down as hour-to-hour wind variability increases. Operationally significant changes in wind generation over short periods of time, from minutes to hours (known as ramping events), highlight this issue. As a first estimate, operationally significant ramps are often considered to be a 20 percent change in power production within 60 minutes or less. However, the actual percent change that is operationally significant varies depending on the characteristics of the power grid and its resources. As the rate and magnitude of a ramp increases, persistence forecasts tend to become less and less accurate for the prediction of short-term wind generation.

While the persistence assumption works for a study like this one, in reality ISO-NE will need better ramp-forecasting tools as wind penetration increases. Such tools would give operators the means to prepare for volatile periods by allocating additional reserves or making other system adjustments. There has been recent progress in this area and better ramp forecasting tools are now being developed. For example, AWS Truepower recently deployed a system for the Electric Reliability Council of Texas (ERCOT) known as the ERCOT Large Ramp Alert System (ELRAS), which provides probabilistic and deterministic ramp event forecast information through a customized web-based interface. ELRAS uses a weather prediction model running in a rapid update cycle, ramp regime-based advanced statistical techniques, and meteorological feature tracking software to predict a range of possible wind ramp scenarios over the next nine hours. It is highly recommended that ISO-NE pursue the development of a similar system tailored to forecast the types of ramps that may impact New England.

Regulation and Operating Reserves

Statistical analysis of load and wind generation profiles as well as ISO-NE operating records of Area Control Error (ACE) performance were used to quantify the impact of increasing penetration of wind generation on regulation and operating reserve requirements.[11]

All differences between the scenarios stem from the different variability characteristics extracted from three years of mesoscale wind production data in the NEWRAM. The methodology and ISO-NE load are the same for each scenario, so wind variability is the only source of differences between scenarios.

Regulation

Significant penetration of wind generation will increase the regulation capacity requirement and will increase the frequency of utilization of these resources. The study identified a need for an increase in the regulation requirement even in the lowest wind penetration scenario (2.5% wind energy), and the requirement would have noticeable increases for higher penetration levels. For example, the average regulation requirement for the load only (i.e., no wind) case was 82 MW. This requirement increases to 161 MW in the 9% wind energy scenario—and to as high as 313 MW in the 20% scenario.

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[11] ACE is a measurement of the instantaneous difference between the net actual and scheduled electric energy flows over the interchange between two regions. It is used to evaluate system control performance in real-time operating conditions. The ISO uses the ACE to dispatch resources that can provide regulation service to the electric grid.

The primary driver for increased regulation requirements due to wind power is the error in short-term wind power forecasting. The economic dispatch process is not equipped to adjust fast enough for the errors inherent in short-term wind forecasting and this error must be balanced by regulating resources. (This error must be accounted for in addition to the load forecasting error.)

Figure 0–3 shows regulation-duration curves for increasing levels of wind penetration. It shows the number of hours per year where regulation needs to be equal to or greater than a given value. For example, the dark blue curve (the left-most curve) shows that between 30 MW and 190 MW of regulation are required for load alone. The 2.5% Partial Queue scenario (the light blue line to the right of the load-only curve) increases the regulation requirement to a range of approximately 40 MW to 210 MW; the overall shape tracks that of the load-only regulation requirement curve. In the higher wind penetration scenarios, this minimum amount of required regulation capacity increases and the average amount of regulation required increases such that the shapes of the curves no longer track that of the load-only curve—this is indicative that the increased regulation capacity will likely be required to be utilized more frequently. The purple curve (the middle curve) shows that a range of approximately 50 MW to 270 MW of regulation is required with 9% wind energy penetration. The yellow and red curves (to the right of the 9% wind penetration curve just discussed) show that the required regulation increases to ranges of approximately 75 MW to 345 MW and approximately 80 MW to 430 MW, respectively. These estimates are based on rigorous statistical analysis of wind and load variability.

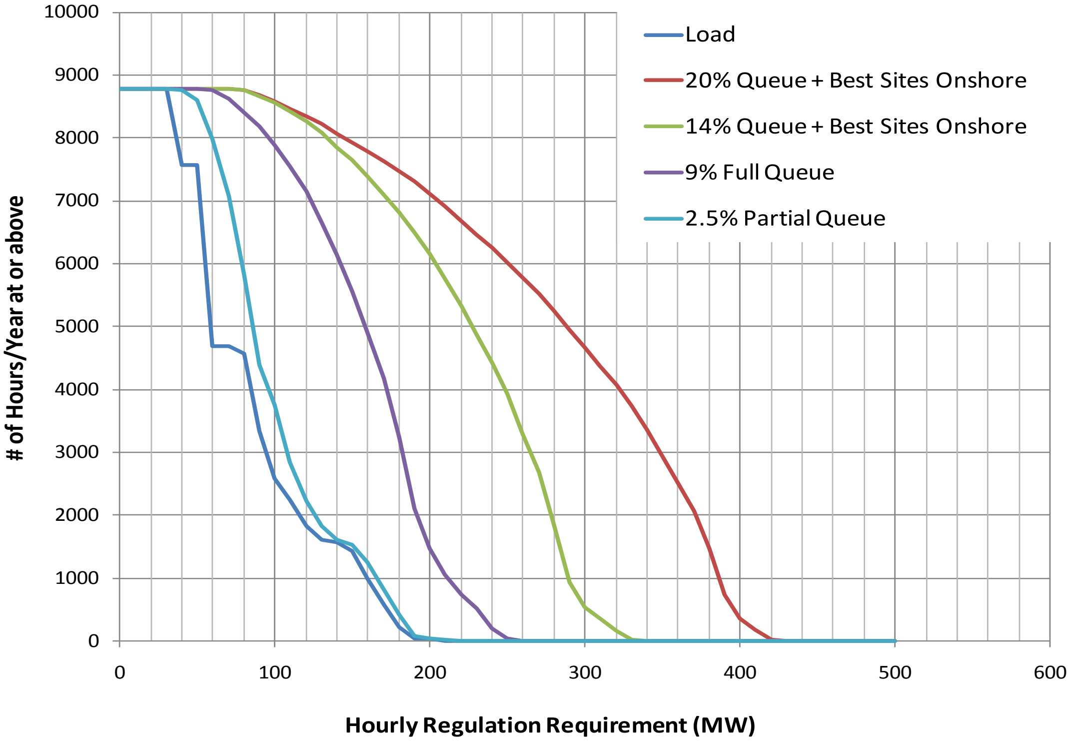

Figure 0–3 Regulation Requirements with Increasing Wind Energy Penetration

At 20% wind energy penetration, the average regulation requirement is estimated to increase from approximately 80 MW without wind, to a high of approximately 315 MW with 20% wind depending on the differences within the scenario. At lower penetration levels, the incremental regulation requirement is smaller. The hourly analysis indicates average regulation requirements would increase to a high of approximately 230 MW with 14% wind energy penetration. At 9% wind energy penetration, the average regulation would increase to approximately 160 MW. At the lowest wind penetration studied (2.5%) average required regulation capability would increase to approximately 100 MW. Alternate calculation methods that include historical records of ACE performance, synthesized 1-minute wind power output, and ISO-NE operating experience suggest that the regulation requirement may increase less than these amounts.

There are some small differences in regulation impacts discernable amongst layouts at the same energy penetration levels. This can be traced directly to the statistics of variability used in these calculations. Based on the ISO-NE wind generation mesoscale data, some scenario layouts of wind generation exhibit higher variability from one ten-minute interval to the next. A number of factors could contribute to this result, including the relative size of the individual plants in the scenario layout (and the impact on spatial and geographic diversity), the local characteristics of the wind resource as replicated in the numerical weather simulations from which the data is generated, and even the number of individual turbines comprising the scenario, as more turbines would imply more spatial diversity. At the same time, however, the differences may be within the margin of uncertainty inherent in the analytical methodologies for calculating regulation impacts. Given these uncertainties, it is difficult to draw concrete conclusions regarding the relative merits of one scenario layout over the others.

ISO-NE routinely analyzes regulation requirements and makes adjustments. As wind generation is developed in the market footprint, similar analyses will take place. Control performance objectives and the empirically observed operating data that includes wind generation should be taken into account in the regulation adjustment process.

ISO-NE’s current practice for monitoring control performance and evaluating reserve policy should be expanded to explicitly include consideration of wind generation once it reaches a threshold where it is visible in operational metrics. A few methods by which this might be done are discussed in Chapter 4, and ISO-NE will likely find other and better ways as their experience with wind generation grows. ISO-NE should collect and archive high-resolution data from each wind generation facility to support these evaluations.

Analysis of these results indicates, assuming no attrition of resources capable of providing regulation capacity, that there may be adequate supply to match the increased regulation requirements under the wind integration scenarios considered. ISO-NE’s business process is robust and is designed to assure regulation adequacy as the required amount of regulation develops over time and the needs of the system change.

Operating Reserves

Additional spinning and non-spinning reserves will be required as wind penetration grows. The analysis indicates that Ten Minute Spinning Reserve (TMSR) would need to be supplemented as penetration grows to maintain current levels of contingency response. Increasing TMSR by the average amount of additional regulation required for wind generation is a potential option to ensure that the spinning reserve available for contingencies would be consistent with current practice.

Using this approach, TMSR would likely need to increase by 310 MW for the 20% energy penetration scenarios, about 125 MW for 14% penetration, and about 80 MW for 9% penetration.

In addition to the penetration level, the amount is also dependent on the following factors:

- The amount of upward movement that can be extracted from the sub-hourly energy market – the analysis indicates that additional Ten Minutes Non-Spinning Reserve (TMNSR), or a separate market product for wind generation, would be needed at 20% penetration
- The current production level of wind generation relative to the aggregate nameplate capacity, and
- The number of times per period (e.g., year) that TMSR and Thirty Minute Operating Reserve (TMOR) can be deployed – for the examples here, it was assumed that these would be deployed 10 times per period.

The amount of additional non-spinning reserve that would be needed under conditions of limited market flexibility and volatile wind generation conditions is about 300 MW for the 20% Best Sites Onshore case, and 150 MW for the 9% Energy Queue case. This incremental amount would maintain the TMNSR designated for contingency events per existing practice, where it is occasionally deployed for load changes. “Volatile wind generation conditions” would ultimately be based on ongoing monitoring and characterization of the operating wind generation. Over time, curves like those in Figure 4-5 would be developed from monitoring data and provide operators with an increasingly confident estimate of the expected amount of wind generation that could be lost over a defined interval.

The additional TMNSR would be used to cover potentially unforecasted extreme changes (reductions) in wind generation. As such, its purpose and frequency of deployment are different from the current TMNSR. This may require consideration of a separate market product that recognizes these differences. ISO-NE should also investigate whether additional TMOR could be substituted to some extent for the TMSR and/or TMNSR requirements related to wind variability.

Due to the increases in TMSR and TMNSR, overall Total Operating Reserve (TOR) increases in all wind energy scenarios. For the 2.5% wind energy scenario, the average required TOR increases from 2,250 MW to 2,270 MW as compared to the no wind energy scenario baseline. The average required TOR increases to approximately 2,600 MW with 14% wind penetration and about 2,750 MW with 20% penetration.

The need for additional reserves varies as a function of wind generation. Therefore, it would be advantageous to have a process for scheduling reserves day-ahead or several hours ahead, based on forecasted hourly wind generation. It may be inefficient to schedule additional reserves using the existing "schedule" approach, by hour of day and season of year, since that may result in carrying excessive reserves for most hours of the year. The process for developing and implementing a day-ahead reserves scheduling process may involve considerable effort and investigation of this process was outside the scope of the NEWIS.

Analysis of Hourly Operations

Production simulation analysis was used at an hourly time-step to investigate operations of the ISO-NE system for all the study scenarios under the previously stated assumptions of transmission expansion, no attrition of dispatchable resources, addition of resources that have cleared in the second Forward Capacity Auction, and the use of all of the technical capability of the system (i.e., exploiting all system flexibility). The results of this analysis indicate that integrating wind generation up to the 24% wind energy scenario is operationally feasible and may reduce average system-wide variable operating costs (i.e., fuel and variable O&M costs) in ISO-NE by $50 to $54 per megawatt-hour of wind energy[12]; however, these results are based on numerous assumptions and hypothetical scenarios developed for modeling purposes only. The reduction in system-wide variable operating cost is essentially the marginal cost of energy, which should not be equated to a reduction in $/MWh for market clearing price (i.e. Locational Marginal Prices--LMPs). Low-priced wind resources could displace marginal resources, but that differential is not the same as reductions in LMPs.

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[12] In essence, this is the cost to replace one MWh of energy from wind generation with one MWh of energy from the next available resource from the assumed fleet of conventional resources.

As mentioned briefly in the introduction to the hourly analysis, the cost information is included only as a byproduct of the production cost analysis and that the study was not intended primarily to compare cost impacts for the various scenarios. These results are not intended to predict outcomes of the future electric system or market conditions and therefore should not be considered the primary basis for evaluating the different scenarios.

Wind energy penetrations of 2.5%, 9%, 14%, 20%, and 24% were evaluated. As wind penetrations were increased up to 24%, there were increasing amounts of ramp down insufficiencies with up to approximately 540 hours where there may potentially be insufficient regulation down capability. There were no violations that occurred for the regulation up. The transmission system with the 4 GW overlay was adequately designed to handle 20% wind energy without significant congestion. The transmission system with the 8 GW overlay was adequately designed to handle 24% wind energy without significant congestion.

Wind generation primarily displaces natural-gas-fired combined cycle generation for all levels of wind penetration, with some coal displacement occurring at higher wind penetrations.

The study showed relatively small increases in use of existing pumped-storage hydro (PSH) for large wind penetrations; because balancing of net load—an essential requirement for large-scale wind integration—was largely provided by the flexibility of the natural-gas-fired generation fleet. It is possible that retirements (attrition) of some generation in the fleet would increase the utilization of PSH, but that was not examined in this study.

The lack of a price signal to increase use of energy storage is the primary reason the study showed small increases in the use of pumped-storage hydro in the higher wind penetrations. For energy arbitrage applications, like pumped storage hydro, a persistent spread in peak and off-peak prices is the most critical economic driver. The differences between on-peak and off-peak prices were small because natural-gas-fired generation remained on the margin most hours of the year. Over the past six years, GE has completed wind integration studies in Texas, California, Ontario, the western region of the United States, and Hawaii. In many of these studies, as the wind power penetration increases, spot prices tend to decrease, particularly during high priced peak hours. The off-peak hours remain relatively the same. Therefore, the peak and off-peak price spread shrinks and no longer has sufficient range for economic storage operation. An example of this can be seen in Figure 0–4. The figure shows the Locational Marginal Price (LMP) for the week of April 1, 2020, for the 20% Best Sites Onshore scenario, using year 2004 wind and load shapes. It also shows the LMP for a case with no wind generation. The price spread decreases substantially, which reduces the economic driver for energy storage due to price arbitrage.

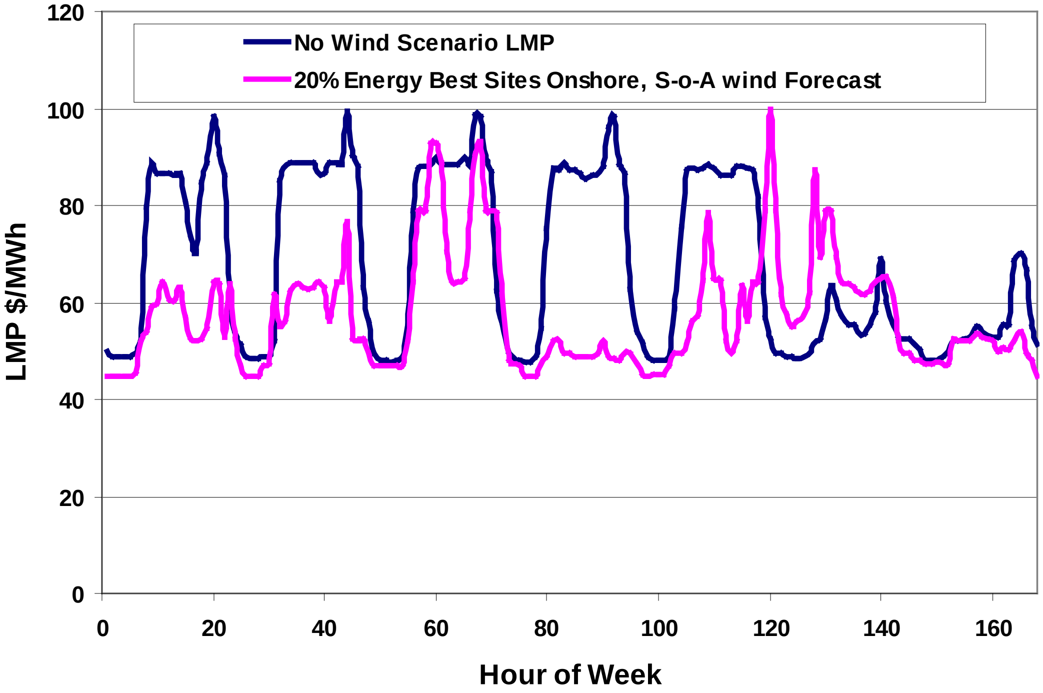

Figure 0–4 LMP for Week of April 1, Comparison of No Wind and 20% Wind Energy

With 20% wind energy penetration, the following impacts were observed on emissions and energy costs:

- NOx emissions were reduced by approximately 6,000 tons per year, a 26% reduction compared to no wind.
- SOx emissions were reduced by approximately 4,000 tons per year, a 6% reduction compared to no wind.
- CO_2 emissions were reduced by approximately 12,000,000 tons per year, a 25% reduction compared to no wind. (Wind generation will not displace other non- CO_2-producing generation, such as hydro and nuclear. Therefore, 20% energy from wind reduces the energy from CO_2-producing generation by 25 to 30%. Considering that wind generation primarily displaces natural-gas-fired generation in New England, the overall CO_2 production declines by 25% with 20% wind energy penetration).
- Average annual Locational Marginal Price (LMP) across ISO-NE[13] was reduced by

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[13] Based on the hourly marginal unit price. The results also do not account for other factors that may change business models of market participants.

  - Best Sites Maritimes - $5/MWh
  - Best Sites Onshore - $6/MWh
  - Best Sites - $9/MWh
  - Best Sites Offshore - $9/MWh
  - Best Sites By State - $11/MWh

Variation in the LMP impact for the different layout alternatives results from the differences in the monthly wind profile as well as the daily profile. For example, the Maritimes layout alternative has slightly less energy in the summer than the other scenarios. Also, the Maritimes has less energy in the afternoon to early evening period, than the other scenarios when looking at the daily average summer profile. As mentioned briefly in the introduction to the hourly analysis, the cost information is included only as a byproduct of the production cost analysis and that the study was not intended primarily to compare cost impacts for the various scenarios. These results are not intended to predict outcomes of the future electric system or market conditions and actual changes in fuel prices, transmission system topology, and resource flexibility will have significant impacts on these results.

Revenue reductions for units not being displaced by wind energy is roughly 5%-10%, based on lower spot prices. For units that are being displaced, their revenue losses are even greater. This will likely lead to higher bids for capacity and may lead to higher bids for energy in order to maintain viability. The correct market signals must be in place in order to ensure that an adequate fleet of flexible resources is maintained.

The study scenarios utilized the transmission system overlays originally developed for the Governors' Study. With these transmission overlays, some scenarios exhibited no transmission congestion and others showed only a few hours per year with transmission congestion. This suggests that somewhat less extensive transmission enhancements might be adequate for the wind penetration levels studied, although further detailed transmission planning studies would be required to fully assess the transmission requirements of any actual wind generation projects.

Capacity Value of Wind Generation

Table 0–1 summarizes the average three-year capacity values for the total New England wind generation for all the scenarios analyzed in this study as calculated using the Loss of Load Expectation (LOLE) methodology where wind generation is treated as a load modifier. As mentioned in the NEWIS Task 2 report, using three years of data only gives some indication as to the variability of the effective capacity of wind generation from year to year. Along with the effective capacity of each scenario, Table 0–1 also includes in brackets the percent of the installed capacity that is offshore for that scenario.

Wind capacity values can vary significantly with wind profiles, load profiles, and siting of the wind generation. For example, the 20% Best Sites Onshore scenario has a wind generation capacity value of 20% while the corresponding 20% Best Sites Offshore scenario has a 32% capacity value. The capacity value of wind generation is dominated by the wind performance during just a few hours of the year when load demand is high. Hence, the capacity value of wind generation can vary significantly from year to year. For example, the 20% Best Sites Offshore scenario had wind capacity values of 27%, 26% and 42% for 2004, 2005 and 2006 wind and load profiles, resulting in the 32% average capacity value shown in Table 0–1.

Table 0–1 Summary of Wind Generation Capacity Values by Scenario and Energy Penetration

Scenario	3-Year Average Capacity Value (%) [% Offshore]	14% Energy 3-Year Average Capacity Value (%) [% Offshore]	20% Energy 3-Year Average Capacity Value (%) [% Offshore]
2.5 % Energy	36% [40%]		
9% Energy (Queue)	28% [20%]		
Onshore		23% [12%]	20% [8%]
Maritimes		26% [13%]	26% [9%]
Best by States		28% [15%]	26% [29%]
Best Sites		35% [47%]	34% [51%]
Offshore		34% [45%]	32% [58%]

High-Level Comparison of Scenario Layouts

For a given penetration of wind energy, differences in the locations of wind plants had very little effect on overall system performance. For example, the system operating costs and operational performance were roughly the same for all the 20% wind energy penetration scenarios analyzed. This is primarily because all the wind layout alternatives had somewhat similar wind profiles (since all of the higher penetration scenarios included the wind generation from the Full Queue), there was no significant congestion on the assumed transmission systems, and the assumed system had considerable flexibility, which made it robust in its capability of managing the uncertainty and variability of additional wind generation across and between the studied scenarios.

The individual metrics (e.g., prices, emissions) are useful in comparing scenarios, but should not be used in isolation to identify a preferred scenario or to predict actual future results.

Offshore wind resources yielded higher capacity factors than onshore resources across all scenarios and also tended to better correlate with the system's electric load. The study indicates that offshore wind resources would have higher capital costs, but generally require less transmission expansion to access the electric grid. Some scenarios with the lowest predicted capital costs (for wind generation only) also required the most amount of transmission because the resources are remote from load centers and the existing transmission system.

Some scenarios that showed the least transmission congestion also required the greatest investment in transmission, so congestion results should not be evaluated apart from transmission expansion requirements. Some scenarios that showed the greatest reductions in LMPs and generator emissions also used wind resources with low capacity factors, which would result in higher capital costs. The complete results are described in the full report.

Recommended Changes to ISO-NE Operating Rules and Practices

Capacity Value: Capacity value of wind generation is a function of many factors, including wind generation profiles for specific wind plants, system load profiles, and the penetration level of wind generation on the ISO-NE system. ISO-NE currently estimates the capacity value using an approximate methodology based on the plant capacity factor during peak load hours. This methodology was examined in Chapter 6 and gives an overall reasonable approximation across the scenarios studied. Given that only three years of data were available for the LOLE calculation and that the results of this method can vary somewhat from year to year, it is recommended that ISO-NE monitor a comparison between its current approximate method and the LOLE/ELCC as operational experience is gained. As wind penetration increases, the Installed Capacity Requirement (ICR) may not accurately account for the intermittent nature of wind resources. GE recommends that the ISO evaluate potential improvements to the calculation of capacity values for wind resources. Given that the capacity value of wind is significantly less than that of typical dispatchable resources, much of the conventional capacity may be required regardless of wind penetration (Section 6.5).

Regulation: ISO-NE presently schedules regulation by time of day and season of year. This has historically worked well as regulation requirements were primarily driven by load, which has predictable diurnal and seasonal patterns. Wind generation does not have such regular patterns. At low levels of wind penetration, the existing process for scheduling regulation should be adequate, since the regulation requirement is not significantly affected by wind. However, with higher penetrations of wind generation (above 9%), it will likely become advantageous to adjust regulation requirements daily, as a function of forecasted and/or actual wind generation on the ISO-NE system. Due to the additional complexity of accommodating large-scale wind power, it is recommended that ISO-NE develop a methodology for calculating the regulation requirements for each hour of the next day, using day-ahead wind generation forecasts.

Determination of actual regulation requirements will need to grow from operating experience, similar to the present methods employed at ISO-NE. (See Section 4.4.3)

TMSR: Spinning reserve is presently dictated by largest contingency (typically 50% of 1,500 MW, the largest credible contingency on the system). ISO-NE presently includes regulation within TMSR. With increased wind penetration, regulation requirements will increase to a level where this practice may need to be changed – probably before the system reaches 9% wind energy penetration. Either regulation should be allocated separately from TMSR, or TMSR should be increased to cover the increased regulation requirements. The latter alternative was assumed for this study, and TMSR values in this report reflect that. (See Section 4.5.1)

TMNSR: Analysis of the production simulations for selected scenarios revealed that additional TMNSR might be needed to respond to large changes in wind generation over periods of tens of minutes to an hour or more. Given the assumption of no attrition of resources, displacement of marginal generation by wind energy may help to ensure that this capacity is available. In other words, some resources that are displaced by wind may be able to participate as fast start TMNSR—if those resources are assumed to continue to be available. A mechanism for securing this capacity as additional TMNSR during periods of volatile wind generation (as shown in the statistical analysis and the characterizations developed for the operating reserve analysis) may need to be developed. The use of TMOR instead of and/or in combination with TMNSR should be investigated (See Section 4.5.3).

Wind Forecast: Day-ahead wind forecasting should be included in the ISO-NE economic day-ahead security constrained unit commitment and reserve adequacy analysis. At the present level of wind penetration, this practice is not critical. At larger penetrations, if wind forecasts are not included in the economic day-ahead unit commitment, then conventional generation may be overcommitted, operating costs may be increased, LMPs may be depressed, the system may have much more spinning reserve margin than is necessary, and wind generation may be curtailed more often than necessary. Analysis performed for the NEWIS indicates that these effects, and hence the case for implementation of a wind power forecast, grows as wind power penetrations increase. Intra-day wind forecasting should also be performed in order to reduce dispatch inefficiencies and provide for situational awareness.

It would also be beneficial for ISO-NE to publish the day-ahead wind forecast along with the day-ahead load forecast, as this would contribute to overall market efficiency. Current practices for publishing the load forecast should be followed for publishing the wind forecast, subject to confidentiality requirements. This allows generation market participants to see the net load forecast and bid accordingly, just as they do with load today (See Section 5.2.4).

Wind Generation and Dispatch: Production simulation results showed increased hours of minimum generation conditions as wind penetration increases, which, given the policy support schemes for wind generation, implies increased frequency of negative LMPs. ISO-NE should not allow wind plants to respond in an uncontrolled manner to negative LMPs (e.g., as self-scheduled resources). Doing so may cause fast and excessive self-curtailment of wind generation. That is, due to their rapid control capability, all affected wind plants could possibly reduce their outputs to zero within a few minutes of receiving an unfavorable price signal. ISO-NE should consider adopting a methodology that sends dispatch signals to wind plants to control their output in a more granular and controlled manner (e.g., with dispatch down commands or specific curtailment orders). This method is recommended in the Task 2 report. NYISO has already implemented a similar method (See Section 5.2.1 for a discussion on the frequency of minimum generation issues).

System Flexibility: Increased wind generation will displace other supply-side resources and reduce flexibility of the dispatchable generation mix—in a manner that is system specific. Any conditions that reduce the system flexibility will potentially, negatively impact the ability of New England to integrate large amounts of wind power. Factors that could potentially reduce system flexibility can be market, regulatory, or operational practices, or system conditions that limit the ability of the system to use the flexibility of the available resources and can include such issues as: strict focus on (and possibly increased regulation of) marginal emissions rates as compared to total overall emissions, decreased external transaction frequency and/or capability, practices that impede the ability of all resources to provide all types of power system products within each resource's technical limits, and/or long-term outages of power system equipment or chronic transmission system congestion.

Strict focus on marginal emissions rates can reduce system flexibility by encouraging generators to operate in a manner that reduces their flexibility (e.g., reducing allowed ramp rates or raising minimum generation levels in order to limit marginal emissions rates) and ignores the fact that as non-emitting resources are added to the system the overall level of emissions is reduced. Due to the variability and imperfect predictability of resources like wind power, dispatchable resources may need to be utilized in different operational modes that in some instances and/or during some hours may actually increase these units' emissions rates (in terms of tons of emittant per MWH of electrical energy), however the total emissions of the system will be reduced. The effects of the increases in marginal emissions rates are expected to be several orders of magnitude smaller than the effect of the overall reductions in emissions. Reduced frequency and/or capability of external interchange limits the ability of balancing areas to share some of the effects of wind power's variability and uncertainty with neighboring systems that at any given time might be better positioned to accommodate these effects. Practices that limit the ability of resources to participate in the power system markets to the full extent of their technical capability may cause the system to operate in a constrained manner, which reduces system flexibility. Self-scheduled generation reduces the flexibility of the dispatchable generation resource and can lead to excessive wind curtailment at higher penetrations of wind generation. It is recommended that ISO-NE examine its policies and practices for self-scheduled generation, and possibly change those policies to encourage more generation to remain under the control of ISO-NE dispatch commands. System flexibility can also be negatively impacted due to expected as well as unforeseen operational conditions of the system that reduce the ability to access and/or utilize the technical flexibility of the system resources. Examples of operational conditions that can negatively impact system flexibility include the long-term outage of resources that provide a large portion of the flexibility on the system, and chronic transmission system congestion or stability and/or voltage constraints along important transmission corridors.

Operating Records: It is recommended that ISO-NE record and save sub-hourly data from existing and new wind plants. System operating records, including forecasted wind, actual wind, forecasted load, and actual load should also be saved. Such data will enable ISO-NE to benchmark actual system operation with respect to system studies. ISO-NE should also periodically examine and analyze this data to learn from the actual performance of the ISO-NE system.

Other Observations from Study Results

Flexible Generation: The ISO-NE system presently has a high percentage of gas-fired generation, which can have good flexibility characteristics (e.g., ramping, turn-down). Using the assumed system, the results showed adequate flexible resources at wind energy penetration levels up to 20%. Also using the assumed system, there are periods of time in the 24% wind energy scenario when much of the natural-gas-fired generation is displaced by the wind generation, leaving less flexible coal and nuclear operating together with the wind generation. In this study, physical limits were used to determine how much units could be turned down when system conditions required such action. ISO-NE will need to be diligent in monitoring excessive self-scheduling, which could limit the apparent flexibility of the generation fleet. ISO-NE may need to investigate operating methods and/or market structures to encourage the generation fleet to make its physical flexibility available for system operations (See Section 5.2.1.2).

Energy Storage: Study results showed no need for additional energy storage capacity on the ISO-NE system given the flexibility provided by the assumed system. However, the need for energy storage may increase if there is attrition of existing flexible resources needed to balance net load and dispatchable resources. It is commonly believed that additional storage is necessary for large-scale wind integration. In New England, wind generation displaces natural-gas-fired generation during both on peak and off-peak periods. Natural-gas-fired generation remains on the margin, and the periodic price differences are usually too small to incent increased utilization of pumped storage hydro-type energy storage, which is why the study results showed PSH utilization increasing only slightly and only at higher levels of wind penetration.

Additional energy storage may have some niche applications in regions where some strategically located storage facilities may economically replace or postpone the need for transmission system upgrades (i.e., mitigate congestion). Also, minute-to-minute type storage may be useful to augment existing regulation resources. But additional large-scale economic arbitrage type storage, like PSH, is likely not necessary (See Section 5.2.1).

Displacement of Energy from Conventional Generation: Energy from wind generation in New England primarily displaces energy from natural-gas-fired generation. Although displacement of fossil-fueled generation might be one of the objectives of regional energy policies, a consequence is that it may radically change the market economics for all resources on the system, but especially for the natural-gas-fired generation resources that are displaced. Although their participation in the ISO-NE market will continue to be important, to serve both energy (especially during summer high-load periods) and capacity requirements, the balance of revenues that resources receive from each of these market segments will change. Since total annual energy output from conventional resources would decline and energy prices also would decline under the study assumptions, capacity prices from these plants will likely need to increase if they are to remain economically viable and therefore able to provide the flexibility required for efficient system operation (See Section 5.2.1).

Dynamic Scheduling: Dynamic scheduling involves scheduling the output of a specific plant or group of plants in one operating area on transmission interties to another operating area. Dynamic scheduling implies that the intertie flows are adjusted on a minute-to-minute basis to follow the output of the dynamically scheduled plants. Most scenarios in this study included all necessary New England wind resources within the ISO-NE operating area, and therefore did not require dynamic scheduling. The Maritimes scenarios assumed that a portion of the ISO-NE wind generation would be imported from wind plants in the Canadian Maritimes using dynamic scheduling, so that ISO-NE would balance the variability due to the imported wind energy. The results showed, given the study assumptions, that ISO-NE has adequate resources to balance the imported Maritimes wind generation.

Load and Distributed Wind Forecasting: This study assumed that load forecast accuracy would remain the same as wind penetration increases. However, a portion of the wind generation added to the ISO-NE system will be distributed generation that may not be observed or controlled by ISO-NE. It will essentially act as a load-modifier. As such, distribution-connected wind generation will negatively affect the accuracy of load forecasts. As long as the amount of this distribution-connected wind generation is fairly small and if ISO-NE is able to account for the magnitude and location of distribution-connected wind plants, it should be possible to include a correction term into the load-forecasting algorithm (See Section 5.3.3).

Technical Requirements for Interconnection of Wind Generation

The Task 2 report, "Technical Requirements for Wind Generation Interconnection and Integration," includes a set of recommendations for interconnecting and integrating wind generation into the ISO-NE power grid. That report was completed before the statistical, production simulation, and reliability analyses of the NEWIS scenarios were performed. The recommendations contained in the Task 2 report were re-examined after the NEWIS scenario analysis was completed and the analysis performed reinforces the need to implement those recommendations. It was determined that no changes to the Task 2 recommendations are warranted at this time based on the results of the scenario analysis. A few of the most significant Task 2 recommendations are summarized below.

Active Power Control: Wind plants must have the capability to accept real-time power schedule commands from the ISO for the purpose of plant output curtailment. Such control would most often be used during periods when wind generation is high and other generating resources are already at minimum load.

AGC Capability: Wind plants should be encouraged to have the capability to accept Automatic Generation Control (AGC) signals, which would enable wind plants to provide regulation. The current ISO-NE market product requires symmetrical regulation, which means that wind generation could only provide this service when it is curtailed. Some other systems have asymmetrical regulation markets where wind generation could be quite effective at down-regulation even under non-curtailed operation, such as when other generation resources have been dispatched down to minimum load and/or other down regulation resources have been exhausted.

Centralized Wind Forecast: ISO-NE should implement a centralized wind power forecasting system that would be used in a manner similar to the existing load forecasting system. Information from the day-ahead wind forecast would be used for unit commitment as well as scheduling regulation and reserves. ISO-NE should also implement intra-day forecasting (e.g. an early warning ramp forecasting system) that will provide improved dispatch efficiency and situational awareness, and alert operators to the likelihood and potential magnitude and direction of wind ramp events.

Communications: Wind plants should have the same level of human operator control and supervision as similar sized conventional plants. Wind plants should also have automated control/monitoring functions, including communications with ISO-NE, to implement operator commands (active/reactive power schedules, voltage schedules, etc.) and provide ISO-NE with the data necessary to support wind forecasting functions. The Task 2 report contains detailed lists of required signals.

Capacity Value: Given that only three years of data were available for the LOLE calculation and that the results of this method can vary somewhat from year to year, it is recommended that ISO-NE should monitor a comparison between its current approximate method and the ELCC method for determining the aggregate capacity value of all wind generation facilities in the operating area, and the calculation should be updated periodically as operational experience is gained. Historical data should be used for existing plants; data from mesoscale simulations could be used for new plants until sufficient operation data is available.

If the recommendations developed and discussed in the Task 2 report are not implemented, it is highly likely that operational difficulties will emerge with significant amounts of wind generation. Two recent examples of some Balancing Authorities experiences with a lack of effective communication and control and/or a lack of an effective wind power forecast and the resulting operational difficulties include having to:

- Implement load-shedding[14] (albeit contracted-for load-shedding), and
- Spill water for hydro resources.[15]

Another example of operational difficulties that could arise includes the experience of some European TSO's with older windplants' lack of ability to participate in voltage control causing the system to sometimes be operated in very inefficient dispatch modes. This lack of voltage control participation, as well as the lack of communication and control capability, was found to have exacerbated the severe European UCTE disturbance in November of 2006[16].

Future Work

Several areas of interest that are candidates for further investigation are suggested by the study results. These include:

Transmission system overlay refinement. The transmission system overlays developed for the Governors' Study and used in this study were shown, based on thermal limit analysis only, to

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[14] ERCOT Event on February 26, 2008: Lessons Learned, available at: http://www1.eere.energy.gov/windandhydro/pdfs/43373.pdf.

[15] "Wind power surge forces BPA to increase spill at Columbia Basin dams" available at: http://www.oregonlive.com/environment/index.ssf/2008/07/columbia_basin_river_managers.html

[16] Final report: System Disturbance on 4 November 2006, available at: https://www.entsoe.eu/fileadmin/user_upload/_library/publications/ce/otherreports/Final-Report-20070130.pdf

have adequate capacity for all scenarios. In fact, some NEWIS scenarios use transmission overlays that were "one size smaller" than those used for the Governors' Study scenarios, and still no or only minimal congestion was observed. Detailed and extensive transmission studies that include stability and voltage limits will be required in order to proceed with specific wind projects or large-scale wind integration.

A future study could start by analyzing wind penetration scenarios using a "copper sheet" approach to evaluate magnitude and duration of congestion due to existing transmission limitations. This would guide the design of specific transmission additions to minimize congestion with increased levels of wind generation.

Sub-hourly performance during challenging periods. A more in-depth investigation of the dynamic performance of the system under conditions of high stress, such as coincident high penetration and high variability could be pursued using additional simulation tools that have been developed recently. Both long-term dynamic (differential equations) simulations and fine time resolution quasi-static time simulations could shed additional insight into the frequency, ACE, CPS2 and other performance measures of the system, as well as providing more quantitative insight into incremental maneuvering duties imposed on the incumbent generation and the impacts of this increased maneuvering on such quantities of interest as emissions and increased generator maintenance. Such analysis could be part of an assessment of possible increased operating costs associated with maneuvering (beyond those captured in the MAPS analysis).

Impacts of Cycling and Maneuvering on Thermal Units. Costs of starting and stopping units, and static impacts on heat rate were reflected in the study to the extent presently possible. However, the understanding of these impacts and the quantification of costs is still inadequate throughout the industry. A deeper quantification of the expected cycling duty, the ability of the thermal generation fleet to respond and an investigation of the costs – O&M, emissions, heat rate, and loss-of-life – would provide clearer guidance for both operating and market design strategies.

Economic Viability and Resource Retirements. The incumbent generating resources, particularly natural-gas-fired generation, will be strongly impacted by large-scale wind generation build-outs like those considered in the study. Investigation should be performed to determine the revenue impacts, and their implications for the long-term viability of the system resources that provide the flexibility required to integrate large-scale wind power. Such investigation could include examination of impact of possible resource retirements driven by reduced energy sales and revenues, and the efficacy of possible market structures for maintaining the necessary resources to maintain system reliability.

Demand Response. A deeper analysis of the efficacy and limitations of various demand-side options for adding system flexibility could help define directions and policies to pursue. Temporal aspects of various demand response options could be further investigated. For example, heating and cooling loads have significant time and duration constraints that will govern their effectiveness for different classes of response. Similarly, some types of commercial and industrial loads may offer options and limitations for providing various ancillary services that will be needed.

Weather, Production, and Forecasting Data. This study was based on sophisticated meso-scale wind modeling. The ISO should start to accumulate actual field data from operating wind plants, from met masts, and from actual forecasts. Further investigation and refinement of study results or use of such data in the suggested sub-hourly performance analysis, would increase confidence in results and may allow for further refinement of ISO plans and practices.

Network Planning Issues. This study was not a transmission planning study. The addition of significant wind generation, particularly multiple plants in close electrical proximity in parts of the New England grid that may be otherwise electrically remote (for example the addition of significant amounts of wind generation in Maine) poses a spectrum of application questions. A detailed investigation of a specific subsystem within New England considering local congestion, voltage control and coordination, control interaction, islanding risk and mitigation, and other engineering issues that span the gap between “interconnection” and “integration” would provide insight and help establish a much needed set of practices for future planning in New England (and elsewhere).