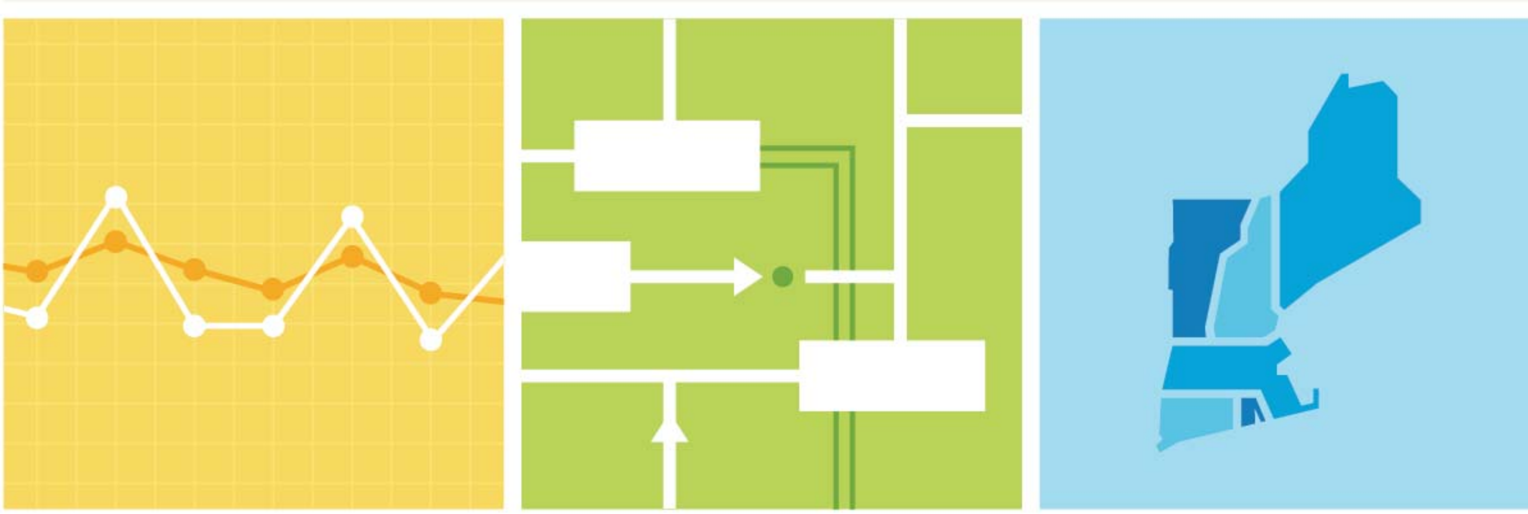
2015 Regional System Plan

System Planning

NOVEMBER 5, 2015



Section 10
Integration of Variable Energy Resources

The integration of large amounts of variable energy resources, including wind and photovoltaics poses new challenges to the electric power system. To address these challenges, the ISO has been conducting a number of studies, gathering operational data and observations, and participating in other projects assessing the development and integration of variable energy resources.

10.1 Potential System Impacts on Fossil Fuel Generators of Integrating Wind and Solar Resources

The US Department of Energy's National Renewable Energy Laboratory (NREL) released the second phase of a study examining the potential impacts of increasing wind and solar power generation on the operators of coal and gas plants in the West (including parts of Canada and Mexico).[290] The report found that to accommodate higher amounts of wind and solar power on the electric power grid, utilities will need to ramp up and ramp down conventional generators more frequently than with less wind and solar on the grid. This report assessed various scenarios of wind and solar penetration and concluded that with wind and solar facilities supplying about 25% of the power in 2020, the projected cost savings of needing less fuel far outweighed the costs associated with increased ramping. In addition, according to this report, overall emissions of SO_2 and NO_X would be reduced despite the impacts of increased ramping.

The ISO will continue to track industry research and monitor the effects that increased amounts of variable energy resources have on system performance, including ramping. The ISO will identify regional needs and work through the stakeholder process to develop regional solutions to any identified issues.

10.2 Integration of Wind Resources

New England has tremendous potential for developing wind resources. The region has developed approximately 850 MW, and almost 4,100 MW is in the interconnection queue. As the amount of wind generation grows, operational forecasts of this variable energy resource take on increasing importance.

10.2.1 Wind Forecasting and Dispatch

On January 15, 2014, the ISO began incorporating wind forecasting into ISO processes, scheduling, and dispatch services. (As of May 2013, the ISO has offered a preliminary informational wind power forecast.) The wind power forecast is exceeding expectations regarding accuracy. In addition to the ISO's use of the wind forecast, wind resources can download the forecast of expected output for their individual units, which can help them build a strategy for bidding in the Day-Ahead Energy Market. As part of phase 1 of this project, the ISO has also created displays that improve operators' situational awareness and is now maintaining historical wind data for future use by the forecast service and in auditing and other analyses. The ISO is working toward the full economic dispatch of wind resources, as well as automated publishing of the aggregate wind energy forecast for the region in phase 2 of this project.

[290] NREL, *The Western Wind and Solar Integration Study Phase 2*, NREL/TP-5500-55588, technical report (DOE, September 2013), http://www1.eere.energy.gov/wind/pdfs/55588.pdf.

10.2.2 Strategic Transmission Analysis—Wind Integration Study

ISO New England is conducting transmission system reliability assessments to identify the nature of the transmission system reinforcements necessary to integrate significant amounts of wind resources into the system. RSP14 discussed how much additional wind energy could be integrated in the State of Maine without major transmission system investment, particularly new lines. RSP15 updates the RSP14 transmission analysis in Maine by more fully accounting for the dynamic regional system behavior and discusses the wind integration analysis for the State of Vermont.

Base case power flow models were developed by adding representative stations for all wind resources in the ISO's queue at the time of the scoping of each portion of the study. Several load conditions were examined, and all wind resources within the area being investigated were increased from zero until a thermal limit was reached for transfer out of the region. System voltage and stability performance were then tested at these thermal limits to determine whether those other limits were more constraining. The studies identified the lower-cost improvements that increased the transfer limit for a region, such as adding reactive devices or series circuit breakers or rebuilding a short transmission line. The generators were modeled with the assumption of robust local voltage control capability at the generation sites. Additional system improvements would be required for interconnections without adequate local voltage control.

The assessment examined the following specific regions:[291]

- Keene Road region in Maine
- Bangor region in Maine
- Wyman region in Maine
- Rumford region in Maine
- Northern region in Vermont
- Central region in Vermont
- Southern region in Vermont

The assessments analyzed thermal, voltage, and stability limits for both local transmission interfaces and broader regional constraints to moving the aggregate wind and other resources from the local regions. The assessments also examined the need for improvements to meet NPCC bulk power system requirements.

10.2.2.1 Summary Results for the Maine Regional Constraint Analysis

Summary results for the Maine regional constraint analysis show that additional wind resources would displace traditional synchronous generator technology and the stability performance benefits of these types of machines.[292] A dynamic reactive device of up to 500 MVAR capability located in central Maine

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[291] Note that the Aroostook, ME, region is considered to need major transmission line construction. ISO New England, *Northern Maine System Performance*, PAC presentation (September 21, 2010), https://smd.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/ceii/mtrls/2010/sep212010/northern_maine.pdf.

[292] *Strategic Transmission Analysis: Wind Integration Study—Stage 1—Maine, Regional Constraints*, PAC presentation (May 21, 2014), https://smd.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/ceii/mtrls/2014/may212014/a4_strategic_transmission_analysis_wind_power_update.pdf.

would likely be needed to integrate new wind resources effectively. At the same time, ensuring that these wind resources directly aid dynamic voltage control could improve the overall system performance during both normal and critical extreme contingencies.

The testing of the regional transmission interfaces in Maine identified the need for additional system reinforcements. These reinforcements include two 345 kV 25 ohm thyristor-controlled series-compensation (TCSC) devices and up to 480 MVAR of 115 kV shunt capacitors throughout Maine.[293] The TCSC devices are necessary to prevent system separation and the interruption of large amounts of resources following severe contingency events in southern New England. The shunt capacitors are required for voltage support in Maine.

The above improvements are insufficient to both improve the performance of the bulk power system and increase regional transfer limits. The study suggests that both these requirements could be met by adding transmission upgrades, such as 1,000 MVAR of synchronous condensers in Maine, in addition to the 500 MVAR dynamic reactive device previously mentioned. The alternative to addressing the BPS performance requirement with the synchronous condensers is the possibility of continually needing widespread substation upgrades throughout southern New England.

10.2.2.2 Summary Results for the Local Maine Regions

The results for the four local Maine regions are summarized below.[294]

Keene Road Region. The ability to accommodate 229 MW (nameplate capability) of wind capacity in this region was analyzed. The studied system would probably not experience thermal violations at this generation level, but a voltage stability issue would occur at levels of wind generation above the simulated amount of 144 MW, and the performance of the system could be unacceptably degraded during extreme contingency conditions. Major transmission construction would likely be needed to address local constraints to additional generation.

Bangor Downeast Region. This area was analyzed for its ability to accommodate 186 MW (nameplate capability) of wind capacity. The 115 kV loop in this region is vulnerable to thermal overloads when a contingency occurs. Low 115 kV voltages also would occur at exports above approximately 130 MW, and the performance of the system could be unacceptably degraded during extreme contingency conditions.

The 186 MW of existing and proposed generation could be integrated with a few relatively small transmission upgrades. System performance is highly sensitive to the location of new plants and the electrical distance from the 115 kV loop. Voltage/transient stability problems are anticipated with amounts of generation greater than the 186 MW studied; major transmission construction would likely be needed to address these voltage/stability constraints.

Wyman Hydro Region. The ability to integrate 418 MW (nameplate capability) of wind capacity, including existing resources, was analyzed for this region. The 2015 system would probably not experience significant thermal violations during the summer and winter but likely would experience thermal constraints during spring and fall when high hydro and wind conditions exist. Low 115 kV and 345 kV

[293] TCSCs are series capacitors that can change their impedance within a fraction of a cycle. They are a type of flexible alternating-current transmission system (FACTS) device that uses a *thyristor*—a power electronics component that provides the ability to switch output. (See Section 11.3.1 for more on FACTS devices.)

[294] *Strategic Transmission Analysis: Wind Integration Study*, PAC presentation (December 18, 2013), https://smd.iso-ne.com/committees/comm_wkgrps/prtcpnts_comm/pac/ceii/mtrls/2013/dec182013/a4_wind_study.pdf.

voltages could be experienced, and the performance of the BPS could be unacceptably degraded during extreme contingency conditions.

These local constraints to the added wind generation may be addressed without major transmission construction for up to 418 MW of wind capacity. This result recognizes reasonably anticipated seasonal variations of plant output, provided that each new wind plant is interconnected with a physically and economically realistic amount of dynamic reactive compensation. Transmission improvements would include items such as the addition of series circuit breakers, the rebuilding of short sections of transmission lines, and the addition of reactive devices.

Rumford Region. This area was analyzed for its ability to accommodate 130 MW (nameplate capability) of wind capacity. No thermal limitations would be expected at this generation level. Low 115 kV and 345 kV voltages could be experienced for normal design contingencies, and the performance of the system could be unacceptably degraded during extreme contingency conditions.

Upgrades would be needed to integrate existing and proposed generation. Local constraints could be addressed without major transmission line construction. System performance is interdependent with the Wyman Hydro region, and the transmission upgrades indicated for this region would also address constraints for Rumford region's generators. This analysis does not indicate the extent to which generation could be added before minor or major transmission construction would become necessary.

10.2.2.3 Summary Results for the Local Vermont Regions

The results for the three local Vermont regions are summarized below:

Northern Vermont Region. The ability to accommodate 287 MW (nameplate capability) of wind in this area was analyzed. The Highgate HVDC connection to Québec was modeled at full import of 216 MW (measured at the New England side of the terminal) during the analysis. Due to the single loop nature of the transmission system in this region, a thermal limit of 213 MW was observed under winter load and line-rating conditions, when the wind would be expected to be at its maximum output. The analysis also considered the integration of the wind resources under summer, shoulder load, and light-load conditions. Thermal transmission constraints caused the summer limit on wind generation to be 120 MW of operating capability. However, the expected typical output of 287 MW of nameplate wind generation in the summer period was estimated to be 86 MW, and the expected maximum output was estimated to be 186 MW.

Similarly, in the shoulder and light-load scenarios, limitations were identified that would permit expected wind generation output under typical output conditions but be restrictive under maximum expected output levels for these seasons. No minor transmission upgrades were identified that could increase the thermal limits identified in the analysis. Stability analysis revealed that additional reactive support would be required at Jay Tap and Highgate to meet the minimum operating voltage requirement at Highgate and accommodate wind up to the seasonal thermal limits. In total, a little over 100 MVAR of reactive support would need to be added in these two locations, a mix of static capacitors and synchronous condensers.

Central Vermont Region. The ability to accommodate 165 MW (nameplate capability) of wind in this area was analyzed. This area has a relatively strong 345 kV backbone, so no thermal or stability reliability violations were observed at this level of wind output. Therefore, no major transmission improvements would be necessary at this level of wind production. The existing system could accommodate 231 MW (nameplate capability) of wind generation, operating at full output, before the 115 kV system would begin to experience thermal overloads.

Southern Vermont Region. The ability to accommodate 95 MW of wind in this area was analyzed. Under winter conditions, this area could accommodate most of this capacity—93 MW. However, during summer-, light-, and shoulder-load periods, summer rating thermal constraints on the 69 kV transmission system would limit the total amount of wind that could be accommodated to 81 MW. While this is only 85% of the nameplate capacity of the wind studied, it is above the reasonably expected maximum output of these wind plants in these load periods. This suggests that the 95 MW of nameplate capacity can be accommodated under most reasonably anticipated conditions during the rest of the year.

10.2.2.4 Strategic Transmission Analysis Conclusions

The STA examined the integration of 1,113 MW of wind resources in Maine and 547 MW in Vermont. Of these amounts, all but 85 MW in Maine could be accommodated without major new transmission investment. Transmission system improvements are necessary to address a combination of local and regional transmission constraints and address BPS performance concerns. Additional wind resources planned for the Wyman Hydro and Rumford regions could likely be accommodated without a major new transmission line to the local regions. However, the Keene Road and Bangor regions cannot support much additional wind capacity beyond the amount studied without major new transmission facilities.

Northern Vermont would require new reactive support to accommodate additional wind and would still be thermally constrained below the amount of wind studied but less so in the winter than in other seasons. Central Vermont showed no constraints to the amount of wind in the queue studied (165 MW) and, the study determined that this area would be capable of integrating about 231 MW of wind. Southern Vermont showed only minor constraints. Some risk of curtailment remains at higher wind load levels in the northern and southern regions if only nonmajor upgrades are applied. Major upgrades would be necessary to eliminate the maximum wind-condition restrictions; however, no curtailment would be required at typical wind levels.

10.3 Large-Scale Adoption of Photovoltaic Resources and Other Distributed Generation Resources

New England has witnessed significant growth in the development of solar photovoltaic resources over the past few years, and continued growth of PV is anticipated (see Section 3.3.3). PV installations not counted as ISO resources reduce the summer peak load, and the technology holds promise as a nonemitting source of electric energy that can be reliably and economically integrated into the system. Reliably and economically integrating PV to the electric power system, however, poses some challenges.

Regional PV installations are predominantly small (i.e., less than 10 MW) and state-jurisdictionally interconnected to the distribution system. State policies largely influence the spatial distribution of PV, such that states with more-supportive PV policies (e.g., Massachusetts) are experiencing the most growth of the resource. Existing amounts of PV have not caused noticeable effects on system operation, but impacts are anticipated as penetrations grow. To examine and prepare for the potential effects of large-scale PV development in the region, the ISO has engaged in the initiatives summarized below.

10.3.1 Operational Solar Forecasting

Because the ISO cannot observe or dispatch most PV in the region, these projects act as a modifier of system load that must be accurately forecasted in the short-term to support the efficient administration of the day-ahead market and the reliable operation of the system. As PV penetrations continue to grow and displace energy production from other resources, PV power production will introduce increased variability and uncertainty to the system and eventually will have an impact on system operations (e.g., result in the need for increased reserve, regulation, and ramping). As such, new forecasting techniques will be required to account for PV generation appropriately.

In early 2013, the ISO began participating in a three-year, DOE-funded project to improve the state of the science of solar forecasting.[295] The results of this project will assist the ISO in developing ways of incorporating the load-reducing effects of PV into improved load-forecasting processes required to support the efficient and reliable integration of increasing amounts of PV.

10.3.2 Potential Reliability Impacts of PV

Because of the differences between the state-jurisdictional interconnection standards that apply to most PV facilities and the FERC-jurisdictional standards that apply to larger, conventional generators, PV exhibits different electrical characteristics during system conditions typical of grid disturbances (e.g., low-voltage conditions during an unexpected outage of a large generator or transmission facility). The ISO participated in an EPRI evaluation of the potential reliability impacts of large amounts of distributed generation, such as PV.[296]

The ISO asked the region's utilities about their interconnection standards, and the responses indicated that most PV units meet the existing IEEE 1547 standards.[297] These standards were designed for relatively small penetrations of DG and do not require PV resources to be able to "ride through" a fault on the transmission system.

A high-level screening conducted by the ISO showed the potential loss of PV resulting from faults on the transmission system. The following maps in Figure 10-1, of Connecticut and Massachusetts, show the areas where PV facilities are likely to trip off line because of low voltage in the event of a fault on the 345 kV transmission system. This could result in thermal or stability problems and could cause the need for additional transmission upgrades. As PV penetrations grow, the severity of this potential problem could also grow.

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[295] On December 27, 2012, the DOE Solar Program awarded funding to the IBM Thomas J. Watson Research Center (DOE Award No. DE-EE0006017). More information is available at DOE, "Improving the Accuracy of Solar Forecasting Funding Opportunity," webpage (n.d.), http://energy.gov/eere/sunshot/improving-accuracy-solar-forecasting-funding-opportunity and DOE, "Watt-Sun: A Multiscale, Multimodel, Machine-Learning Solar Forecasting Methodology," web article (n.d.), http://energy.gov/eere/sunshot/watt-sun-multi-scale-multi-model-machine-learning-solar-forecasting-technology.

[296] EPRI, *Recommended Settings for Voltage and Frequency Ride-Through of Distributed Energy Resources* (May 8, 2015), http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002006203.

[297] Institute of Electrical and Electronics Engineers (IEEE) 1547 establishes criteria and requirements for the interconnection of distributed resources with electric power systems. This document provides a uniform standard for the performance, operation, testing, safety considerations, and maintenance of the interconnection. See "IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems," webpage (2014), http://grouper.ieee.org/groups/scc21/1547/1547_index.html.

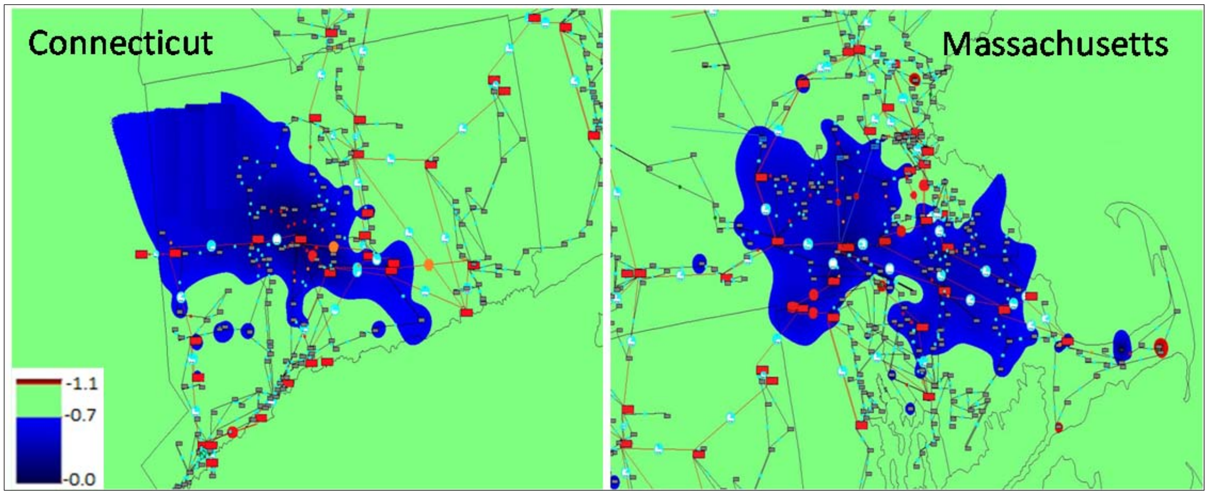

Figure 10-1: Areas (in blue), in Connecticut (left) and Massachusetts (right), where PV resources are likely to trip off line because of low voltage in the event of a fault on the 345 kV transmission system.

Notes: The key refers to per-unit voltage. Also see *Impacts of Transmission System Contingencies on Distributed Generation—Overview*, PAC presentation (December 16, 2013), http://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/othr/distributed_generation_frcst/2013mtrls/dec162013/dg_transmission_impacts.pdf.

A sensitivity analysis also was conducted, which indicates that low voltage will be more widespread when local generation is not operating, for example, on a spring day with light load and high wind and solar generation.

The ISO is working with the New England states, distribution utilities, and IEEE and other international experts to ensure that the future interconnection standards for PV (and other inverter-interfaced DG resources) better coordinate with broader system reliability requirements.[298] The ISO will participate in revising the IEEE standards with the aim of improving the coordination of distribution system needs and transmission system performance requirements without imposing barriers to the development of distributed generation.[299]

The ISO also will continue to actively track the growth of PV in the region and evaluate its potential impacts on the efficient administration of wholesale electricity markets and the reliable operation and planning of the region's electric power system. Because many other regions of North America also are witnessing the large-scale adoption of PV, the ISO also is engaging with other ISO/RTOs to share relevant methods and experience.

10.3.3 Other Challenges of PV Integration

The growth in DG presents some challenges for grid operators and planners. Challenges for the ISO include the following:

- Difficulty obtaining and managing the amount of data concerning DG resources, including their size, location, and operational characteristics

[298] IEEE 1547 and interconnection requirements for low/high-voltage ride through, low/high-frequency ride through, ramp rates, and others.

[299] *DG Interconnection Issues*, PAC presentation (July 7, 2015), http://www.iso-ne.com/static-assets/documents/2015/07/a2_dg_interconnection_issues_update.pdf.

- A current inability to observe and control most DG resources in real time
- A need to better understand the impacts on system operations of the increasing amounts of DG, including ramping, reserve, and regulation requirements

The ISO's work with the regional stakeholders will help position the region to best integrate rapidly growing DG resources in a way that maintains reliability and allows the states to realize the public policy benefits they have identified as the basis for their DG programs.

10.3.4 Eastern Renewable Generation Integration Study

NREL is nearing completion of the *Eastern Renewable Generation Integration Study* (ERGIS).[300] The study simulated operations of the Eastern Interconnection with high penetrations of wind and solar generation and sought to advance the state-of-the-art of previous large-scale renewables integration studies, such as the Eastern Wind Integration and Transmission Study (EWITS).[301] The ERGIS study was the first to examine large penetrations of solar power in the eastern United States, including scenarios with solar penetrations of up to 174 GW, and used the most detailed representation of the entire Eastern Interconnection to date.

10.4 Economic Performance of the System and Other Studies

Economic studies provide metrics depicting various system-expansion scenarios and the pros and cons associated with selected possible future scenarios. These scenarios could assess system performance at a higher level, such as possible additional imports from Canada, resource retirements, and resource additions, but do not assess scenarios and the performance of individual asset owners. The key metrics developed include estimates of production costs, transmission congestion, electric energy costs for New England consumers, and a number of others. These metrics suggest the most economical locations for resource development and the least economical locations for resource retirements.

10.4.1 2011 to 2013 Economic Studies and 2015 Economic Study Request

The 2011, 2012, and 2013 economic studies analyzed several of the strategic issues the region is addressing.[302]

- The *2011 Economic Study* examined the effects of integrating varying amounts of wind on production costs, load-serving entity (LSE) expenses, and emissions, as well as the need for transmission development, to enable wind resources to serve the region's load centers.
- The *2012 Economic Study* highlighted the least suitable locations for unit retirements and the most suitable locations for developing new resources using congestion as the key metric

[300] NREL, "Eastern Renewable Generation Integration Study," webpage (2015), http://www.nrel.gov/electricity/transmission/eastern_renewable.html.

[301] EnerNex, *Eastern Wind Integration and Transmission Study* (NREL, 2011), http://www.nrel.gov/docs/fy11osti/47078.pdf.

[302] ISO New England, *2012 Economic Study*, final report (April 30, 2014), http://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2014/a9_2012_economic_study_final.pdf, and *2011 Economic Study*, final report (March 31, 2014), http://www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/prtcpnts_comm/pac/reports/2014/2011_eco_study_final.pdf. The *2013 Economic Study* (October 30, 2014), http://www.iso-ne.com/static-assets/documents/2014/10/2013_economic_study_final.pdf.

associated with each location. The study showed the effects of using various amounts of energy efficiency and low-emitting resources, including renewable energy, as well as other technologies.

- The *2013 Economic Study* examined the economic and environmental effects of increasing the acceptable loss-of-source (LOS) limits in New England.

The ISO did not conduct a 2014 economic study because it did not receive any requests for one or propose one.

The ISO received three economic study requests in 2015 to assess the following topics:[303]

- Onshore wind development in the Keene Road area of northern Maine and the effects of upgrading the Keene Road Interface.
- Onshore wind development in Maine and the effects of implementing the conceptual improvements identified in the *Strategic Transmission Analysis: Wind Integration Study*.
- Offshore wind development and the effects of adding transmission improvements that relieve potential bottlenecks

Approximately 320 MW of wind resources are located in the Keene Road area, and over 90 MW of additional future development is proposed for interconnecting to the 115 kV system in the area. The first economic study will develop metrics to quantify the effects of curtailments expected on the post MPRP system (see Section 6.3). The effect of potential improvements in the Keene Road area will then be evaluated to quantify the possible benefits associated with market efficiency transmission upgrades (see Sections 2.1.1.2 and 6.5.2) that could allow the wind resources to operate without the current level of constraints. Additional analysis beyond the economic study would be required to fully develop any METUs.

The second proposed economic study will investigate scenarios of wind-resource development and will show the effect of the conceptual transmission system expansion in Maine. As discussed in Section 10.2.2, *the Strategic Transmission Analysis: Wind Integration Study* identified a number of conceptual transmission upgrades that could relieve constraints to existing and planned onshore wind development throughout Maine. This study may inform the region on the cost and benefits of pursuing these transmission upgrades.

The third 2015 economic study will examine offshore wind development near Rhode Island and Southeast Massachusetts. The analysis includes the effects of imports from Canada over new interconnections and the development of onshore wind generation in northern New England. The study also considers the retirement of older nuclear, coal-fired, and oil-fired generating units. This study may also inform the region of the need to pursue public policy transmission upgrades.

[303] *2015 Economic Studies Keene Road Upgrades Scope of Work—Revised Draft*, PAC presentation (June 17, 2015), http://www.iso-ne.com/static-assets/documents/2015/06/a9_2015_economic_studies_keene_rd_upgrades_scope_of_work_revised_draft.pdf. *2015 Economic Studies Strategic Transmission Analysis—On-Shore Wind Integration Scope of Work—Revised Draft*, PAC presentation (June 17, 2015), http://www.iso-ne.com/static-assets/documents/2015/06/a9_2015_economic_studies_on_shore_wind_integration_scope_of_work_revised_draft.pdf. *2015 Economic Study—Off-Shore Wind Scope of Work—Revised Draft*, PAC presentation (June 17, 2015), http://www.iso-ne.com/static-assets/documents/2015/06/a9_2015_economic_studies_off_shore_wind_scope_of_work_revised_draft.pdf.

10.4.2 Generic Capital Costs of New Supply Resources

The comparison of the energy market revenues with the annual revenue requirements (also called annual carrying charges) provides some relative measures of the economic viability of different resource types and how these measures change under various scenarios. Each resource type's annual fixed costs include its capital, operations, and maintenance costs. These fixed costs can be calculated from estimates of annual carrying charges derived from representative capital costs for each resource type. These typically are 15% to 25% of the capital costs.

In support of the economic studies for 2015, the ISO updated the generic capital costs for new resources, as shown in Table 10-1.[304] The focus of this update was on the resource technologies in the ISO Generator Interconnection Queue and those participating in the FCM. The updated plant costs are from DOE's Energy Information Administration (EIA), the Electric Power Research Institute (EPRI), the Brattle Group, ISO New England, and the Western Electricity Coordinating Council (WECC).[305]

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[304] ISO New England, *Generic Capital Costs of Supply-Side Resources*, PAC presentation (April 28, 2015), http://iso-ne.com/static-assets/documents/2015/04/a4_generic_costs_of_supply_resources.pdf.

[305] EIA, *Assumptions to the Annual Energy Outlook 2014*, "Electricity Market Module" (2014), www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf, and *Capital Cost for Electricity Plants* (April 12, 2013), www.eia.gov/forecasts/capitalcost/.

EPRI, *Program on Technology Innovation: Integrated Generation Technology Options 2012* (February 10, 2013), www.epri.com/abstracts/Pages/ProductAbstract.aspx?productId=000000000001026656.

ISO New England, "Net CONE Estimates for Potential Reference Technologies," Excel table (March 2014), www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/mrkts_comm/mrkts/mtrls/2014/mar192014/a02_iso_net_cone_capital_budgeting_model_03_14_14.xlsx, and "Summary of Construction Cash Flows" Excel table (September 2013), www.iso-ne.com/static-assets/documents/committees/comm_wkgrps/mrkts_comm/mrkts/mtrls/2013/oct892013/a06_iso_ortp_analysis_final_results_10_02_13.xlsx.

WECC, *Capital Cost Review of Power Generation Technologies* (March 2014), www.wecc.biz/Reliability/2014_TEPPC_Generation_CapCost_Report_E3.pdf.

Table 10-1
Generic Capital Costs of New Supply-Side Resources

Technology Type[a]	Plant Size[b] (MW)	Heat Rate[b] (Btu/kWh)	Total Plant Cost[c] ($/kW)
Advanced combined cycle (CC)	340–400	6,430–7,525	1,020–2,085
Advanced gas turbine (GT)	190–210	9,090–9,750	675–1,430
Biomass	20–100	12,350–13,500	3,600–8,180
Conventional CC	550–730	7,000–7,525	825–1,150
Conventional GT	85–420	10,575–10,815	630–970
Natural gas fuel cells	10	9,500	7,045
Offshore wind	200–400	N/A	3,100–6,190
Onshore wind	50–200	N/A	1,750–2,400
Solar photovoltaic	5–150	N/A	2,000–3,565

(a) Technology types in the queue as of April 1, 2015.

(b) Additional information about these data is available in the ISO PAC presentation, *Generic Capital Costs of Supply-Side Resources* (April 28, 2015), http://www.iso-ne.com/static-assets/documents/2015/04/a4_generic_costs_of_supply_resources.pdf.

(c) The total plant costs are also referred to as the overnight construction costs or overnight capital costs.

Specific project costs may differ from generic estimates due to a number of different factors, such as the following:

- Resource size
- State of technology development
- Changes in material, labor, and overhead costs
- Supply-chain backlogs or oversupply
- Specific site requirements
- Regional cost differences
- Difficulties in obtaining site and technology approvals

In addition, experience suggests that many construction projects encounter unforeseen design and construction problems that tend to increase costs.

10.5 Summary

The ISO continues to analyze wind integration and advance the implementation of wind forecasting and dispatch. While the level of wind resources has not yet triggered additional requirements, the ISO is working toward increasing system flexibility and has increased its operating reserve to address resource performance issues. The ISO is improving the modeling of wind resources and has updated the process for pursuing elective upgrades.

The *Strategic Transmission Analysis: Wind Integration Study* developed conceptual additions to the transmission system that would enable onshore wind resources to reliably serve load. Economic studies are showing the effects of integrating varying amounts of wind generation on production cost, load-serving energy expenses, and congestion. These studies also are indicating the need for transmission development to enable wind resources to serve the region's load centers. The ISO will continue to engage stakeholders on the issues challenging the wind-interconnection process and the performance of the system with wind resources in locally constrained areas.

Economic studies have examined various scenarios of changes in transfer capabilities, resource expansion, and retirement scenarios. When completed, the 2015 economic study of the Keene Road area may identify needs that could lead to a market efficiency transmission upgrade. The 2015 economic studies of onshore wind expansion and offshore wind expansion may trigger the need for further analysis leading to public policy transmission upgrades.

Additional work remains on incorporating the effects of PV in improved short-term load-forecasting tools for use by system operators and fully addressing the potential reliability risks posed by growing penetrations of PV.