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EXCERPT

THE EFFECTS OF INTEGRATING WIND POWER ON TRANSMISSION SYSTEM PLANNING, RELIABILITY, AND OPERATIONS

Report on Phase 2:

System Performance Evaluation

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1 Introduction

1.1 Background

In response to emerging market conditions, and in recognition of the unique operating characteristics of wind generation, the New York Independent System Operator (NYISO) and New York State Energy Research and Development Authority (NYSERDA) commissioned a joint study to produce empirical information that will assist the NYISO in evaluating the reliability implications of increased wind generation. The work was divided into two phases.

Phase 1, Preliminary Overall Reliability Assessment, was completed in early 2004. This initial phase provided a preliminary, overall, screening assessment of the impact of large-scale wind generation on the reliability of the New York State Bulk Power System (NYSBPS). This assessment included:

- Review of world experience with wind generation, focusing on regions that have integrated significant penetration of wind resources into their power grids
- Fatal flaw power flow analysis to determine the maximum power output at prospective wind generation sites that can be accommodated by the existing transmission system infrastructure, considering thermal ratings of transmission lines
- Reliability analysis to determine the contribution of prospective wind generation towards meeting New York State requirements for Loss Of Load Expectation (LOLE)
- Review of current planning and operating practices to identify New York State Reliability Council (NYSRC), Northeast Power Coordinating Council (NPCC), North-American Electric Reliability Council (NERC), and NYISO rules, policies, and criteria that may require modification to be compatible with high penetration of wind generation

Phase 2 builds on what was learned in Phase 1. A base case wind scenario with 3,300 MW of wind generation (10% of NY State peak load) was selected for analysis. Operation of the NYSBPS with 3,300 MW of wind was evaluated in numerous ways, considering impacts on the following aspects of grid performance:

- Reliability and generation capacity
- Forecast accuracy
- Operation of day-ahead and hour-ahead markets
- Economic dispatch and load following
- Regulation
- Stability performance following major disturbances to the grid.

Detailed analysis of economic impacts and evaluation of possible generator retirements were not included in the scope of this study.

Results of these Phase 2 analyses are presented in this report.

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1.2 Wind Generation Scenario

Starting from the original 10,026 MW of wind generation at 101 sites evaluated in Phase 1, two alternate scenarios with 3,300 MW of wind generation were considered. The project team selected a scenario with 3,300 MW of wind generation in 33 locations across New York State. Table 1.1 shows the location (by zone) of the wind farms included in the study. The lower portion of Table 1.1 lists the "Superzones" used by NY State Department of Public Service (DPS) for the RPS study. Load zones within the New York Control Area are illustrated in Figure 1.1.

The wind generation in Zone K, Long Island, is located offshore. The rest of the sites are land-based wind farms. The 600 MW site in Zone K was divided into 5 separate wind farms for interconnection into the Long Island transmission grid. Thus, the 33 wind sites are modeled in loadflow and stability simulations as 37 individual wind farms.

The majority of the interconnections were at the 115kV voltage level and above. Four of the Long Island interconnections were at the 69kV voltage level. No interconnections were below 69kV.

As a point of reference, the NYISO queue of proposed new generation presently has a total of 1939 MW in wind projects.

Table 1.1 Study Scenario – Wind and Load MW by Zone

	Total Potential Wind Generation	2008 Noncoincident Peak Load	Wind MW in Study Scenario	Wind as % of Peak Load
Zone A	3,070	2,910	684.2	24%
Zone B	1,197	2,016	358.5	18%
Zone C	1,306	2,922	569.7	19%
Zone D	483	902	322.6	36%
Zone E	2,832	1,592	399.8	25%
Zone F	434	2,260	260.6	12%
Zone G	105	2,260	104.6	5%
Zone H	0	972	0.0	0%
Zone I	0	1,608	0.0	0%
Zone J	0	11,988	0.0	0%
Zone K	600	5,275	600.0	11%
sum	10,026	34,704	3300.0	10%
DPS Zn 1	8,887	10,342	2334.8	23%
DPS Zn 2	538	7,099	365.2	5%
DPS Zn 3	600	17,263	600.0	3%
sum	10,026	34,704	3300.0	10%

Notes: DPS Zn 1 = Zones A + B + C + D + E
DPS Zn 2 = Zones F + G + H
DPS Zn 3 = Zones I + K

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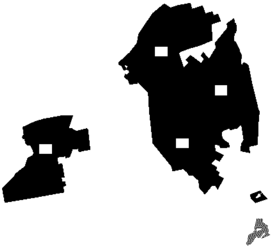

Figure 1.1 New York Control Area Load Zones

The majority of the wind generation in the study scenario is located in upstate NY, Zones A through E. In those zones, penetration of wind generation is 23% of peak zonal load. The 600 MW of offshore wind generation in Zone K represents 11% of peak load in that zone.

The model of the New York State Bulk Power System (NYSBPS) used in this study was derived from NYISO's 2008 transmission and generation modeled. Zonal load profiles were derived from measured data from years 2001-2003, scaled upward to be consistent with projected load levels in 2008. Selection of year 2008 for the study scenario is conservative, since 3,300 MW of operational wind generation is more than would be expected by that time.

Wind turbine-generators were assumed to have characteristics consistent with present state-of-the-art technology, and included continuously controllable reactive power capability (0.95 power factor at point of interconnection), voltage regulation, and low-voltage ride-through (LVRT).

1.3 Timescales for Power System Planning and Operations

The power system is a dynamic system, subject to continuously changing conditions, some of which can be anticipated and some of which cannot. The primary function of the power system is

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to serve a continuously varying customer load. From a control perspective, the load is the primary independent variable – the driver to which all the controllable elements in the power system must be positioned and respond. There are annual, seasonal, daily, minute-to-minute and second-to-second changes in the amount (and character) of load served by the system. The reliability of the system then becomes dependent on the ability of the system to accommodate expected and unexpected changes and disturbances while maintaining quality and continuity of service to the customers.

As illustrated in Figure 1.2, there are several time frames of variability, and each time frame has corresponding planning requirements, operating practices, information requirements, economic implications and technical challenges. Much of the analysis presented in this report is aimed at quantitatively evaluating the impact of significant wind variability in each of the time frames on the reliability and performance of the NYSBPS.

Figure 1.2 shows four timeframes covering progressively shorter periods of time. In the longest timeframe, planners must look several years into the future to determine the infrastructure requirements of the system. This timeframe includes the time required to permit and build new physical infrastructure. In the next faster timeframe, day-to-day planning and operations must prepare the system for the upcoming diurnal load cycles. In this time frame, decisions on unit commitment and dispatch of resources must be made. Operating practices must ensure reliable operation with the available resources. During the actual day of operation, the generation must change on an hour-to-hour and minute-to-minute basis. This is the fastest time frame in which economics and human decision-making play a substantial role. Unit commitment and scheduling decisions made the day ahead are implemented and refined to meet the changing load. In NY State, the economic dispatch process issues load following commands to individual generators at 5-minute intervals. In the fastest time frame (at the bottom of the figure), cycle-to-cyle and second-to-second variations in the system are handled primarily by automated controls. The system automatic controls are hierarchical, with all individual generating facilities exhibiting specific behaviors in response to changes in the system that are locally observable (i.e. are detected at the generating plant or substation). In addition, a subset of generators provide regulation by following commands from the centralized automatic generation control (AGC), to meet overall system control objectives including scheduled interchange and system frequency.

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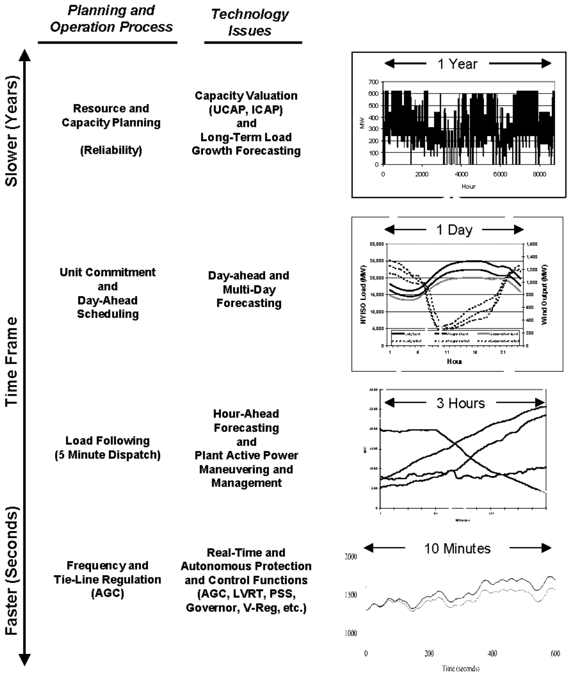

Figure 1.2 Time Scales for System Planning and Operation Processes

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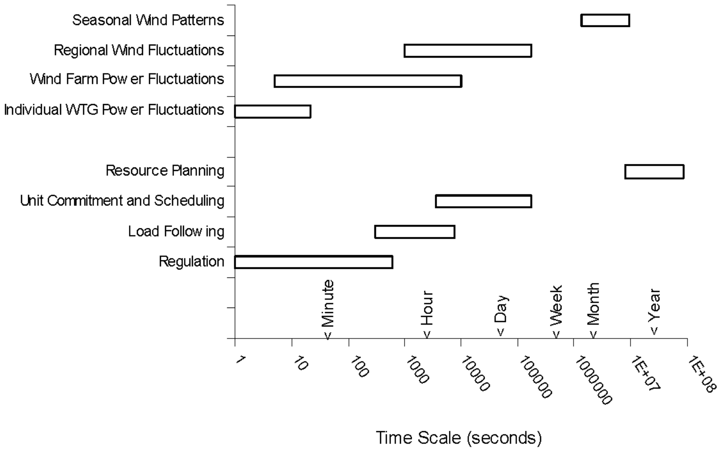

Figure 1.3 Wind Variability and Impact on System Operation Processes

Wind, as a variable and largely undispatchable generating resource, will impact all of these planning and operation processes. Wind variability has its own characteristics and time frames. As with system load, there are seasonal, diurnal, hour-to-hour , minute-to-minute and second-to-second variations. In the case of wind generation, as the time frame decreases the correlation between wind generating resources drops.[i] This is shown in the upper portion of Figure 1.3, where the spatial aspect of wind variation is correlated to the time-scale of temporal variations. Individual wind turbine-generators (WTGs) commonly experience power output variations in the one-second to several-minute timeframe. When many WTGs are grouped together in a wind farm, the short-term variations of individual WTGs are attenuated as a percentage of the aggregate, and the dominant power output variations for the entire wind farm occur in the minute-to-hour time frame. Similarly, the minute-to-minute power output of individual wind farms are attenuated in systems with multiple wind farms, leaving regional wind fluctuations in the hour-to-day time frame as the dominant system-wide effect. Seasonal wind patterns, of course, fall into the several-month timeframe.

The lower portion of Figure 1.3 shows how these wind variations relate to the four groups of planning and operation processes identified in Figure 1.2.

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1.4 Technical Approach

The technical approach for this project addresses the range of processes involved in the planning and operation of the NYSBPS, over the range of timescales from seconds to years. The analysis focuses on the overall performance of the NYSBPS with a high penetration of wind generation, and does not address all localized effects related to each individual wind farm.

The bulk of the technical analysis was grouped into four major areas as described below.

1.4.1 Forecast Accuracy

The accuracy of the wind forecast affects unit commitment and operating reserve policies. Accuracy of wind generation forecasting was evaluated, and related to the historical accuracy of load forecasts used in the day-ahead market.

1.4.2 Wind and Load Variability

The NYSBPS already deals with significant variability in system load. Wind generation, as a variable power source, adds to the total variability that the NYSBPS must accommodate. The analysis of variability addressed the both major contributors to variability over several time frames:

Variability:

- Variability due to load alone
- Variability due to wind alone
- Combined variability due to load and wind, synchronized over the same calendar periods.

Time Frames:

- Hourly
- 5-minutes (load-following; economic dispatch)
- Seconds (regulation, AGC)

This analysis used consistent sets of historical wind data and historical load data, for the same time periods.

1.4.3 Operational Impact

Operational impacts cover a range of time scales, from seconds to multiple hours. Operation of the NYSBPS was simulated with and without wind generation (per the study scenario) as follows:

- Simulation of statewide operations for an entire year using MAPS, focusing on dispatch and unit commitment issues as a function of wind forecast accuracy.

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- Quasi-steady-state simulation of selected 3-hour periods for wind and load variability, focusing on issues that affect load following.
- Stability simulation of selected 10-minute periods, focusing on regulation and other short-term control and protection issues (voltage regulation, low-voltage ride-through, AGC, etc.)

1.4.4 Effective Capacity

Using the Multi-Area Reliability Simulation (MARS) program, the effective capacity of wind generation, was quantified by comparing it with a typical fossil-fired power plant. This analysis includes consideration of the seasonal and diurnal variability in wind generation output relative to periods of peak system load, when generating resources have the greatest impact of overall system reliability as measured by loss-of-load probability (LOLP).

In addition to quantifying the likely range of unforced capacity (UCAP) for wind generation in NY State, approximate techniques for calculating the UCAP of individual wind farms were developed.

1.5 Data

Technical information and data for this study were obtained from the following sources:

- NYISO provided power flow and stability datasets, historical operating data for years 1999-2003, and contingency lists for the NYSBPS and NYSRC reliability datasets.
- AWS TrueWind provided data on potential wind generation sites in NY State, wind MW generation at those sites based on historical weather data, and technical information related to wind generation and wind forecasting.
- NYSDPS provided generation fuel cost and heat rate data from the preliminary RPS analyses.

Appendix A contains detailed descriptions of data provided by NYISO and AWS TrueWind.

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2 Executive Summary

This study evaluated the impact of wind generation on the New York State Bulk Power System (NYSBPS) over a broad range of subject areas, including planning, operation, economics, and reliability. Key results and conclusions are summarized here. Details of the analysis, and the reasoning behind the conclusions, are further explained in Chapters 3-8.

2.1 Study Scenario for Wind Generation

The technical analysis for this study focused on a wind generation scenario that included a total of 3,300 MW of wind generation in 33 locations throughout New York State (see Table 2.1). Most of the wind sites are located upstate, but there is one large offshore facility near Long Island (Zone K). The total amount of wind generation (nameplate rating) in this scenario corresponds to approximately 10% of New York State's 2008 projected peak load. The majority of the wind farm interconnections were at the 115kV voltage level and above. Some interconnections for the Long Island site were at the 69kV voltage level. No interconnections were below 69kV.

Table 2.1 Wind Generation Included In Study Scenario

Location	Wind Generation MW	Wind Generation as % of 2008 Peak Load
Zone A	684.2	24%
Zone B	358.5	18%
Zone C	569.7	19%
Zone D	322.6	36%
Zone E	399.8	25%
Zone F	260.6	12%
Zone G	104.6	5%
Zone H	0.0	0%
Zone I	0.0	0%
Zone J	0.0	0%
Zone K	600.0	11%
Total for NY	3300.0	10%

Powerflow and operational models for the study scenario were derived from NYISO's 2008 system model. Hourly and shorter-term load profiles were based on actual historical data from years 2001-2003, but were scaled to match the projected load for 2008. Profiles of wind generation at the 33 locations were derived from historical weather records for years 2001-2003, so wind generation in the study scenario was treated as though the wind generators were actually in operation during those years.

Observations and conclusions presented in this report are based on analysis of this study scenario.

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2.2 Impact on System Planning

A wide variety of standards, policies and criteria were reviewed to assess their impact on wind generation, and to determine if changes were needed to accommodate wind generation. In general, it was found that the existing rules and criteria could be applied to wind generation. A few specific items are discussed below.

2.2.1 NYISO System Reliability Impact Study (SRIS)

NYISO's SRIS is intended to confirm that a new facility complies with applicable reliability standards, to assess the impact of the new facility on the reliability of the pre-existing power system, to evaluate alternatives for eliminating adverse impacts (if any), and assess the impact of the new facility on transmission transfer limits. The SRIS policy is directly applicable to wind generation in its present form.

2.2.2 NYSRC Reliability Rules for Planning and Operation

NYSRC reliability rules are outlined in the document *NYSRC Reliability Rules for Planning and Operating the New York State Power System*, which addresses both resource adequacy and system security. A few minor changes related to planning studies are recommended:

The rules for steady-state analysis require evaluation of single-element (N-1) and extreme contingencies. Normally, loss of one generator in a multi-generator power plant would be a single-element contingency. Wind farms are comprised of many wind turbine-generators connected to a common interconnection bus. It is recommended that the loss of the entire wind farm be considered a single-element contingency for the purpose of NYSRC reliability criteria. However, simultaneous loss of multiple wind farms due to loss of wind in not a credible event. No changes to NYSRC rules for extreme contingencies, or multiple-element outages, are recommended.

NYSRC rules for stability analysis require evaluation of both design criteria and extreme faults. No changes to these rules or their interpretation are required for wind generation.

2.2.3 Generation Interconnection Requirements

In the Phase 1 report, it was recommended that New York State adopt some of the interconnection requirements that have emerged from the experiences of other systems. Specifically, New York State should require all new wind farms to have the following features:

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- Voltage regulation at the Point-Of-Interconnection, with a guaranteed power factor range
- Low-voltage ride-through (LVRT)
- A specified level of monitoring, metering, and event recording
- Power curtailment capability (enables system operator to impose a limit on wind farm power output)

The above features are implemented in wind farms around the world, and are proven technology.

During Phase 2, technical analysis was performed to evaluate some of these features with respect to performance of the NYSBPS. Specifically, the impact of voltage regulation and low voltage ride through (LVRT) on system performance was demonstrated. The results showed that voltage regulation with a ±0.95 power factor range improves system response to disturbances, ensuring a faster voltage recovery and reduced post-fault voltage dips. In addition, LVRT ensures that wind farms remain connected to the NYSBPS under low voltage conditions due to faults or other system disturbances, and mitigates concerns about loss of multiple wind farms due to system events. Good performance was demonstrated with LVRT parameters that are less aggressive than the emerging industry consensus. It is recommended that New York adopt the emerging LVRT specification.

No operating conditions were found to justify the need for wind power curtailment at a statewide level (i.e., backing down all wind generators at the same time). However, for system reliability reasons, NYISO should require a power curtailment feature on new wind farms as a mechanism to posture the power system to handle temporary local transmission limitations (e.g., line out of service) or in anticipation of severe weather (e.g., intentionally curtail wind generation in advance of a severe storm affecting a large portion of the state). Such curtailment could be done by NYISO sending maximum power orders to wind farm operators (similar to the existing process for re-dispatching a thermal generator via the plant operator) or via SCADA for the case of unmanned generation facilities. This type of curtailment is envisioned as a farm-level function, not necessarily a turbine-level function. For example, if NYISO needed to limit power output of a specific wind farm due to a temporary transmission line outage, the wind farm operator could temporarily curtail generation by limiting output or shutting down a portion of the wind turbines in the wind farm. This is the same as would be done at any other dispatchable generating facility in New York State under the same circumstances.

Interconnection requirements are different for each transmission owner in New York State. In general, standards for interconnection of wind turbines are the same as for other generation.

Thus, frequency and voltage ranges, power factor ranges and other protection requirements remain largely unchanged. However, some features, such as governor control and power system stabilizer (PSS), are either technically impractical now or inappropriate for wind generators.

Presently, New York State has varied requirements for generator power factor. NERC Planning Standards require the following, "*At continuous rated power output, new synchronous generators should have an overexcited power factor capability, measured at the generator terminals, of 0.9 or less and an underexcited power factor capability of 0.95 or less.*"[ii] Niagara Mohawk's requirements are consistent with those of NERC, but LIPA requires generators to have a power factor capability of 0.90 leading to 0.90 lagging at the point of delivery.

FERC NOPR RM05-4-000 (dated January 24, 2005) proposes that "*a wind plant shall maintain a power factor within the range of 0.95 leading to 0.95 lagging, measured at the high voltage side of the wind plant substation transformer(s).*"[iii] The requirement for measurement at the high side voltage recognizes the distributed nature of wind plants. The FERC NOPR power factor range measured at the high side bus is consistent with NERC requirements at generator terminals.

It is recommended that wind generation facilities meet power factor requirements consistent with other generation facilities in New York State and with existing local interconnection criteria, but translated to the high side voltage of the wind plant substation transformer. NYISO and New York State transmission owners may wish to re-evaluate the power factor requirements after FERC enacts a rule.

2.2.4 Future Interconnection Options

In the Phase 1 report, the following features were identified as emerging in response to system needs, and should be considered by New York State in the future as they become available:

- Ability to set power ramp rates
- Governor functions
- Reserve functions
- Zero-power voltage regulation

During Phase 2, technical analysis was performed to evaluate one of these features with respect to performance of the NYSBPS. Specifically, the ability to set power ramp rates for wind farms was demonstrated. The example ramp rate limit function resulted in a decrease in statewide

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regulation requirements at the expense of wind energy production. Therefore, such a function should only be used in specific applications to ensure system reliability.

2.3 Impact on System Operations

Table 2.2 provides a condensed summary of many key study results, arranged according to time scale. The following sections discuss each item in detail.

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Table 2.2 Summary of Key Analytical Results for Study Scenario

Time Scale	Technical Issue	Without Wind Generation	With Wind Generation	Comments
Years	UCAP of Wind Generation	$UCAP_{land\text{-}based} \cong 10\%$ $UCAP_{offshore} \cong 36\%$ (one site in L.I.)		• UCAP is site-specific • Simple calculation method proposed
Days	Day-Ahead Forecasting and Unit Commitment	Forecasting error: $\sigma \cong$ 700-800 MW	Forecasting error: $\sigma \cong$ 850-950 MW	• Incremental increase can be accommodated by existing processes and resources in NY State • Even without forecasts, wind energy displaces conventional generation, reduces system operating costs, and reduces emissions. • Accurate wind forecasts can improve results by another 30%
Hours	Hourly Variability	σ = 858 MW	σ = 910 MW	• Incremental increase can be accommodated by existing processes and resources in NY State
	Largest Hourly Load Rise	2575 MW	2756 MW	• Incremental increase can be accommodated by existing processes and resources in NY State
Minutes	Load Following (5-min Variability)	σ = 54.4 MW	σ = 56.2 MW	• Incremental increase can be accommodated by existing processes and resources in NY State
Seconds	Regulation	225 to 275 MW	36 MW increase required to maintain same performance	• NYISO presently exceeds NERC criteria • May still meet minimum NERC criteria with existing regulating capability
	Spinning Reserve	1200 MW	1200 MW	• No change to spinning reserve requirement
	Stability	8% post-fault voltage dip (typical)	5% post-fault voltage dip (typical)	• State-of-the-art wind generators do not participate in power swings, and improve post-fault response of the interconnected power grid.

Note: σ = standard deviation

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2.3.1 Forecasting and Market Operations

NYISO's day-ahead market presently uses day-ahead load forecasts as part of the generation commitment and scheduling process. The error between forecast load and actual load introduces a level of uncertainty that must be accommodated by NYISO's operating practices. Wind generation introduces another element of uncertainty. Analysis of wind forecast performance for the study scenario shows that errors in day-ahead wind generation forecasts have standard deviations of approximately 400 MW, or 12% of the aggregate rating of all the wind generators (3,300 MW).

Figure 2.1 shows the standard deviations of load forecast error, wind forecast error, and combined "Load minus Wind" forecast error for 11 selected months of years 2001-2003. The figure shows that total forecasting error (Load-Wind) is somewhat higher than the forecasting error due to load alone. For example, in the peak load months (points on the right-hand side), the total forecast error increases from 700-800 MW without wind generation (Load alone) to 850-950 MW with 3,300 MW of wind generation (Load-Wind). NYISO operational processes to deal with uncertainty in load forecasting already exist. The same processes can be used to handle the increase in forecast uncertainty due to wind generation.

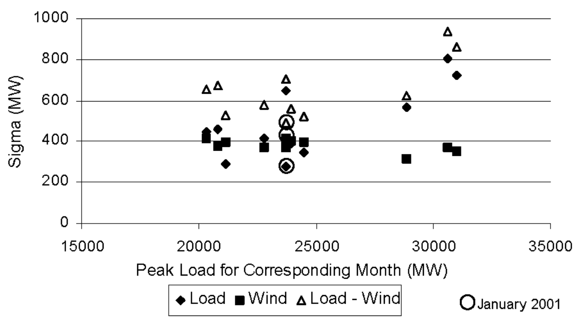

Figure 2.1 Standard Deviation of Day-Ahead Forecast Errors

Accuracy of wind forecasts improves as the lead-time decreases. For the study scenario, errors in hour-ahead wind generation forecasts are expected to have standard deviations of approximately 145 MW, or 4.2%.

Wind forecast uncertainties are of sufficient magnitude at the levels of penetration examined in this study to warrant the use of state-of-the-art forecasting. Data collection from existing and new wind farms should proceed immediately, in order to provide input to, and increase the fidelity of, wind forecasts for when the system achieves higher levels of penetration. New York should also consider meteorological data collection and analysis from proposed and promising wind generation locations in order to aid and accelerate the integration of high fidelity wind forecasting into NYISO's operating practices.

The existing day-ahead and hour-ahead energy markets in New York have sufficient flexibility to accommodate wind generation without any significant changes. It may also be advantageous for the forecasting to be performed from a central location to ensure a consistency of methodologies and so that changing weather patterns can be noted quickly. With these factors in place wind generation can be held accountable to similar standards as conventional generation in terms of meeting their day-ahead forecast, with one exception; imbalance penalties should not be imposed on wind generation Wind projects would need to settle discrepancies between their forecast and actual outputs in the energy balancing market. However, because wind is largely non-dispatchable, any additional penalties for imbalance should be eliminated. The FERC Order 888 allows imbalance *penalties* to be applied to generators that operate outside of their schedule. As applied in New York, any "overgeneration" can be accepted without payment and any "undergeneration" is priced at the *greater* of 150% of the spot price or $100/MWh. Strict application of these policies in the MAPS analysis performed would result in the loss of roughly 90% of the wind generation revenue, which would be disastrous to their future development. The intent of the penalties is to prevent generators from "gaming" the market but their application to intermittent resources such as wind and solar would result in negative and unintended consequences. If a wind generator forecasted 100 MW for a particular hour but can only produce 80 MW due to a lack of wind then no amount of penalties can get them to produce the remaining 20 MW. Their only option would be to bid less, or zero, in the day ahead market and possibly even bid low in the hour ahead market. However, the MAPS analysis showed that as much as 25% of the value of the wind energy to the system could be lost if it is not properly accounted in the day ahead commitment process. Any imbalance penalties for under-generation would tend to encourage underbidding the day ahead forecast, to the detriment of the entire system.

In order to take advantage of the spatial diversity of multiple plants, it may also be appropriate to aggregate wind generation on a zonal or regional basis rather than treating them as individual plants.

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Wind forecasting may be performed in either a centralized or decentralized manner. With either approach, forecasts would be generated for each individual wind farm. However, centralized wind forecasting has several advantages that the NYISO may wish to consider:

- Application of a consistent methodology, which should achieve more consistent results across projects
- More effective identification of approaching weather systems affecting all wind plants, to warn the ISO of impending large shifts in wind generation
- Use of data from each plant to improve the forecasts at other plants. For example, a change in output of one plant might signal a similar change in other plants downstream of the first. Individual forecasters would not have access to the data from other projects to make this possible.

Care should be taken in the structuring of any financial incentives that may be offered to encourage the development of wind generation. The market for wind generation (including incentives) should be structured to:

- Reward the accuracy of wind generation forecasts, and
- encourage wind generators to reduce production during periods of light load and excessive generation.

The second item above is particularly critical to overall system reliability. If excessive wind generation causes the NYISO to shut down critical base-load generators with long shutdown/restart cycle times, the system could be placed in a position of reduced reliability. The market for wind power should be structured so that wind generators have clear financial incentives to reduce output when energy spot prices are very low (or negative).

2.3.2 Hourly Variability

Load and wind production vary from day-to-day and hour-to-hour, exhibiting characteristic diurnal patterns. The wind variability increases the inherent variability that already exists due to loads. Table 2.3 shows the changes in hourly variability due to the addition of wind generation, expressed as standard deviations (σ).

Table 2.3 Hourly Variability With and Without Wind Generation

	Without Wind	With Wind	Increase
Statewide	858 MW	910 MW	6%
Superzone A-E	268 MW	313 MW	17%
Zone K	149 MW	171 MW	15%

System operators give special attention to periods of peak demand and rapid rise in load. The summer morning load rise, especially during periods of sustained hot weather, presents one of the more severe tests to the system. Figure 2.2 shows the hour-to-hour variability for the load rise period for mornings during June through September. The natural diurnal tendency for wind generation to fall off during this period causes higher rates of rise. In this sample, 31% of the hours have rise rates greater than 2,000 MW/hr without wind, with the worst single hour rising 2,575 MW. With the addition of wind generators, this increases to 34% of hours with rise rates greater than 2,000 MW/hr, and the worst single hourly rise is 2,756 MW. Existing NYISO operating practices are expected to accommodate this increase.

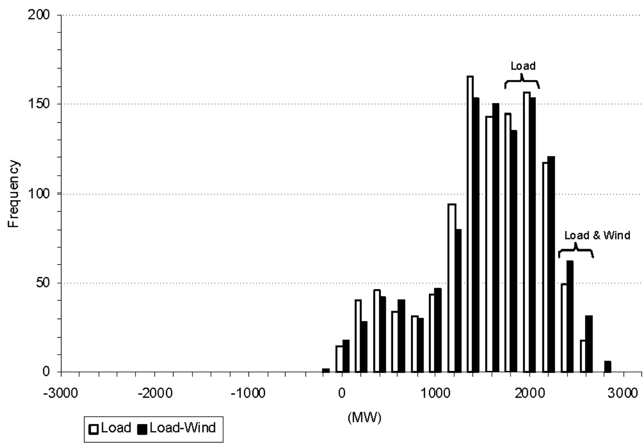

Figure 2.2 Summer Morning Load Rise - Hourly Variability

2.3.3 Load-Following

The impact of 3,300 MW of wind generation imposed on existing load-following performance was evaluated by both statistical analysis and time-response simulations.

NYISO sends economic dispatch commands to generators at 5-minute intervals. Statistical results are summarized as a histogram in Figure 2.3, showing the distribution of 5-minute changes in load with and without wind. These results indicate that wind generation would introduce only a small increase in the load-following duty for generators on economic dispatch. The standard

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deviation of the statewide samples increases by 1.8 MW (3%), from 54.4 MW without wind generation to 56.2 MW with wind generation.

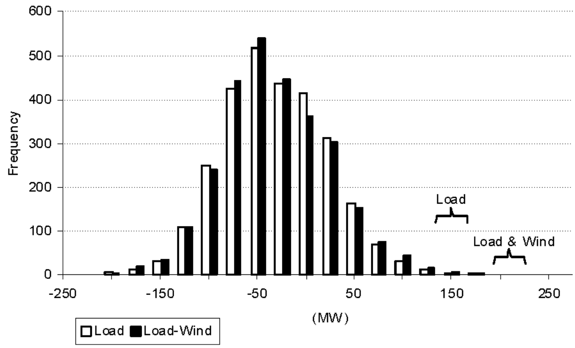

Figure 2.3 Five-Minute Statewide Variability

Quasi-steady-state (QSS) time simulations were performed to evaluate load-following performance during selected periods when both load and wind experienced large changes (e.g., rising load while wind generation declines, and vice-versa). The simulations were for load and wind profiles near the upper extremes of both Figure 2.2 and Figure 2.3, as indicated by the annotations on the figures. The results show that the existing economically dispatched generators would accommodate the increase in load-following duty.

2.3.4 Regulation

NYISO's automatic generation control (AGC) system maintains intertie flows and system frequency by issuing power commands to the regulating units at 6-second intervals. Existing operating practices require 225 MW to 275 MW of regulating units on-line, depending on the season. The impact of 3,300 MW of wind generation imposed on the existing regulating scheme was evaluated by both statistical analysis and stability simulations.

The statistical analysis of the study scenario shows that the standard deviation (σ) of 6-second variability due to load alone is 71 MW. As a check of existing regulation practice, this result suggests that 3σ, or 213 MW, of regulation would cover 99.7% of the time. With the addition of 3,300 MW of wind generation, the standard deviation increases from 71 MW to 83 MW. This implies that a 36 MW (3σ) increase in regulating capability will maintain the existing level of

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regulation performance with the addition of 3,300 MW of wind generation. Stability simulations covering selected 10-minute periods produced similar results.

This conclusion is further reinforced by the results of the 5-minute variability analysis. Variations in periods less than five minutes are addressed by regulation, while longer-term variations are addressed by economic dispatch (load-following). The analysis shows the standard deviation of combined load and wind variability for 5-minute periods is 56.2 MW (up from 54.4 MW due to load alone).

NYISO regulation performance (CPS1 and CPS2) presently exceeds NERC criteria. It is possible that the NYISO grid could accommodate 3,300 MW of wind generation with no increase in NYISO's regulation capability, and still meet minimum NERC criteria.

2.3.5 Spinning Reserves

Spinning reserves are required to cover the largest single contingency that results in a loss of generation. The present requirement is 1,200 MW. Analysis of historical statewide wind data indicates that loss of all wind generation due to abrupt loss of wind in not a credible contingency, and hence, the spinning reserve requirement would not be affected. Short-term changes in wind are stochastic (as are short-term changes in load). A review of the wind plant data revealed no sudden change in wind output in three years that would be sufficiently rapid to qualify as a loss-of-generation contingency.

2.3.6 System Operating Costs

GE’s Multi-Area Production Simulation (MAPS) program was used to simulate the hourly operation of the NYSBPS for several years, with and without wind generation per the study scenario. Several different techniques for integrating wind generation into NYISO’s unit commitment and day-ahead market were considered. The most likely approach involves using day-ahead wind generation forecasts for the unit commitment process, and scheduling wind generation before hydro. The process essentially shifts hydro generation within a several day period to make the best use of wind resources when they are available. Operating cost impacts for this approach are summarized in Table 2.4, based on the 2001 historical hourly load and wind profiles. (Note: System-wide impacts include NYISO, ISO-NE, and PJM.) The MAPS simulation results also indicate a $1.80/MWh average reduction in spot price in New York State.

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Table 2.4 Annual Operating Cost Impacts for 2001 Wind and Load Profiles
(Unit commitment based on wind generation forecast)

	System-Wide	NYISO
Total variable cost reduction *(includes fuel cost, variable O&M, start-up costs, and emission payments)*	$ 430M	$ 350M
Total variable cost reduction per MW-hour of wind generation	$48 / MWh	$39 / MWh
Wind revenue	$ 315M	$ 315M
Non-wind generator revenue reductions	$ 795M	$ 515M
Load payment reductions *(calculated as product of hourly load and the corresponding locational spot price)*	$ 515M	$ 305M

The operating costs depend on how the wind resources are treated in the day-ahead unit commitment process. If wind generation forecasts are not used for unit commitment, then too many units are committed and efficiency of operation suffers. The operating costs for this situation are summarized in Table 2.5. In this case, unit commitment is performed as if no wind generation is expected, and wind energy just “shows up” in the real time market. The results indicate that energy consumers benefit from greater load payment reductions, but non-wind generators suffer due to inefficient operation of committed units. Comparing the system-wide variable cost reductions for these two cases, there is a $430M-$335M = $95M annual benefit to be gained from using wind energy forecasts for day-ahead unit commitment.

Table 2.5 Annual Operating Cost Impacts for 2001 Wind and Load Profiles
(Wind generation not included for unit commitment)

	System-Wide	NYISO
Total variable cost reduction *(includes fuel cost, variable O&M, start-up costs, and emission payments)*	$ 335M	$ 225M
Total variable cost reduction per MW-hour of wind generation	$38 / MWh	$25 / MWh
Wind revenue	$ 305M	$ 305M
Non-wind generator revenue reductions	$ 960M	$ 600M
Load payment reductions *(calculated as product of hourly load and the corresponding locational spot price)*	$ 720M	$ 455M

Any economic incentives that may be offered to wind generators should be designed to encourage use of state-of-the-art forecasting and active participation in the day-ahead power market.

2.3.7 Energy Displacement and Emission Reductions

Energy produced by wind generators will displace energy that would have been provided by other generators. Considering wind and load profiles for years 2001 and 2002, 65% of the energy displaced by wind generation would come from natural gas, 15% from coal, 10% from oil, and 10% from imports. As with the economic impacts discussed above, the unit commitment process affects the relative proportions of energy displaced, but the general trend is the same regardless of how wind generation is treated in the unit commitment process.

By displacing energy from fossil-fired generators, wind generation causes reductions in emissions from those generators. Based on wind and load profiles for years 2001 and 2002, annual NOx emissions would be reduced by 6,400 tons and SOx emissions would be reduced by 12,000 tons.

2.3.8 Transmission Congestion

Because most of the wind generation is located in upstate New York, transmission flows increase from upstate to downstate with the addition of wind generation. Figure 2.4 shows a time-duration curve of the UPNY-SENY (upstate New York to Southeast New York) interface flow for year 2008, with and without wind generation per the study scenario. Without wind generation, interface flow is at its limit for approximately 1100 hours. Wind generation increases the number of hours at limit to 1300. Most of the time, the interface is not limited and increased flows due to wind generation are accommodated.

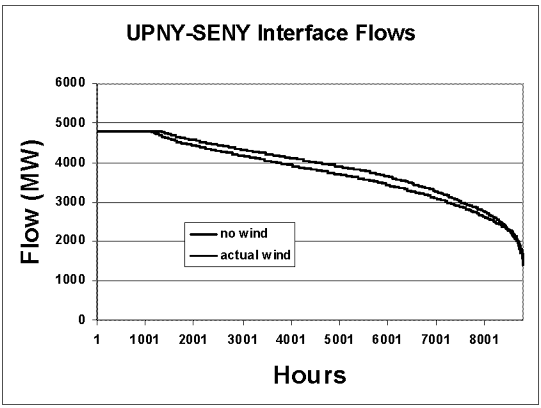

Figure 2.4 Duration Curve of Hourly Flows on UPNY-SENY Interface

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2.4 Impact on System Reliability

2.4.1 Effective Capacity of Wind Generators

The effective capacity of wind generation in the study scenario was quantified using rigorous loss-of-load probability (LOLP) calculations with the Multi-Area Reliability Simulation (MARS) program. The results show that the effective capacities, UCAP, of the inland wind sites in New York are about 10% of their rated capacities, even though their energy capacity factors are on the order of 30%. This is due to both the seasonal and daily patterns of the wind generation being largely "out-of-phase" with NYISO load patterns. The offshore wind generation site near Long Island exhibits both annual and peak period effective capacities on the order of 40% - nearly equal to their energy capacity factors. The higher effective capacity is due to the daily wind patterns peaking several hours earlier in the day than the rest of the inland wind sites and therefore being much more in line with the load demand.

An approximate methodology for calculating effective capacity, UCAP, of wind generation was demonstrated. A wind generator's effective capacity can be estimated from its energy capacity factor during a four-hour peak load period (1:00 pm to 5:00 pm) in the summer months. This method produces results in close agreement with the full LOLP analytical methodology.

2.4.2 System Stability

The transient stability behavior of wind generation, particularly vector controlled WTGs, is significantly different from that of conventional synchronous generation. The net result of this behavior difference is that wind farms generally exhibit better stability behavior than equivalent (same size and location) conventional synchronous generation. In fact, simulation results demonstrate that overall stability performance of the NYSBPS is better with 3,300 MW of wind generation than it is without wind generation. Both post-fault voltage dips and oscillations in interface flows are improved with the addition of vector controlled wind turbine-generators.

It is recommended that New York State require all new wind farms to include voltage regulation and low voltage ride through (LVRT) features. Voltage regulation improves system response to disturbances, ensuring a faster voltage recovery and reduced post-fault voltage dips. LVRT ensures that wind farms remain connected to the NYSBPS under low voltage conditions due to faults or other system disturbances. Good performance was demonstrated with LVRT parameters that are less aggressive than the emerging industry consensus. However, it is recommended that NYS adopt the emerging LVRT specification (15% voltage at the point of interconnection for 625

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milliseconds), consistent with the recent FERC NOPR on wind generation interconnection requirements.

2.5 Conclusions

Based on the results of this study, it is expected that the NYSBPS can reliably accommodate at least 10% penetration, 3,300 MW, of wind generation with only minor adjustments to its existing planning, operation, and reliability practices. This conclusion is subject to several assumptions incorporated in the development of the study scenario:

- Individual wind farms installed in NY State would require approval per the existing NYISO procedures, including SRIS.
- Ratings of wind farms would need to be within the capacity of local transmission facilities, or subject to local constraints.
- Wind farms would include state-of-the-art technology, with reactive power, voltage regulation, and LVRT capabilities consistent with the recommendations in this report.

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