Solar Impact on Grid Operations
- An Initial Assessment



6/30/2016

Caution and Disclaimer

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Executive Summary

A recent study by the National Renewable Energy Laboratory (NREL)[1] concluded that the nationwide technical potential for rooftop solar photovoltaic (PV) system is 1,118 gigawatts (GW) of installed capacity and 1,432 terawatt-hours (TWh) of annual energy generation, equal to 39% of total national electric sales. The NREL study found that New York State has the potential to install 46.4 GW of rooftop solar PV systems, which could produce 55.3 TWh of annual energy generation, 37.4% of New York's annual electric sales. The NREL acknowledges that its assessments "provide an upper bound on potential deployment rather than a prediction of actual deployment." Nevertheless, the NREL findings clearly indicate that the impact of rooftop solar PV systems on the future of the electric system can be significant.

The growth of solar PV energy as a source of electric generation is being strongly influenced by various public policy initiatives, including programs established by the State of New York in the State Energy Plan.

The NY-Sun Initiative (NY-Sun) was announced in 2012. In April 2014, following two successful years of solar PV installations, a commitment of nearly $1 billion was made to NY-Sun. NY-Sun brings together and expands programs administered by the New York State Energy Research and Development Authority (NYSERDA), Long Island Power Authority (LIPA), PSEG Long Island, and the New York Power Authority (NYPA) and is designed to result in 3,000 MW of behind-the-meter installed PV capacity by the end of 2023. In 2016, financing for the NY-Sun program was incorporated in the Clean Energy Fund, one component of New York State's Reforming the Energy Vision (REV) initiative.

The establishment of the NY-Sun Initiative, its ambitious goal, and the success of the program to date has prompted the NYISO to investigate a number of specific potential grid operation needs presented by the increasing penetration of intermittent solar and wind resources. This investigation focused on the impact of distributed, behind-the-meter solar PV installations (rather than utility-scale solar resources). Specifically, this study has four primary areas of investigation:

- development of hourly solar profiles and a 15-year solar PV projection in the New York Control Area (NYCA);
- "lessons learned" and integration studies from other regions experiencing significant growth in solar PV and wind resources;
- potential reliability concerns associated with the frequency and voltage ride-through characteristics of solar PV installations; and
- the impact of various levels of solar PV and wind penetration on NYCA's regulation requirements used in grid operations to balance the system and maintain frequency and other key parameters.

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[1] *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, National Renewable Energy Laboratory Technical Report (NREL/TP-6A20-65298), January 2016.

From an operational perspective, power systems are dynamic and are affected by factors that change each second, minute, hour, day, season, and year. In each and every time frame of operation, it is essential that balance be maintained between the load on the system and the available supply of generation. In the very short time frames (seconds-to-minutes), bulk power system reliability is almost entirely maintained by automatic equipment and control systems, such as automatic generation control (AGC). In the intermediate to longer time frames, system operators are required to constantly adjust, commit, or decommit generation to keep the load and generation balance. Operational decisions are continuously challenged by the amount of expected load and its variability in real time. The magnitude of this challenge increases in proportion to the additions of intermittent solar- and wind-generating resources.

Historically, generators have been central-station facilities and served the needs of the electric system as base load, cycling, or peaking units. Base load facilities, such as nuclear and large steam generators, most efficiently generate at flat output and generally run to meet the system's base requirements. Other units such as combined-cycle facilities are considered to be cycling units and can ramp up and down to serve that portion of the system's load that varies through the course of the day. Peaking units are generally smaller units that are dispatched to serve load for short durations during system peak conditions.

Solar PV and wind generation are considered intermittent resources and are distinct from base load, cycling, or peaking generating facilities in that their output fluctuates frequently in response to conditions beyond the generator operator's control and in a manner that is more difficult for the system operators to forecast. This is compounded in the case of behind-the-meter solar PV whose output is not directly visible to the system operators in real-time.

Due to this lack of visibility and the variable and uncertain nature of renewable generation output, the patterns of solar PV and wind generation managed by system operations have more in common with load than with conventional generation. Therefore, the primary metric of interest in assessing the impact of solar and wind on system operations is "net load," which is defined as the load (customer electric usage or demand) minus solar PV and wind generation. To provide balance to the variable nature of the net load, other resources (*e.g.*, fossil-fueled generation, hydroelectric resources, and energy storage devices) must be able to respond with load following capability.

This study analyzes and draws its conclusions on how the increased penetration of intermittent resources would impact NYCA system conditions using the current system resource mix and the best information currently available on the operating characteristics of solar and wind resources. The NYISO actively tracks new and improved technologies that may enhance system operations and planning (perhaps at lower costs). However, at this time, the application and physical characteristics of emerging technologies such as electric storage (including the potential use of electric vehicles as a medium for storage) is too premature to model. Going forward, the increased penetration of such technologies and advances in the efficiencies of intermittent resources, among other factors, may change the baseline conditions that may affect how the studied build-out of large-scale renewable resources would impact system operations and, therefore, require this study to be revisited.

This solar integration study addressed several important aspects of solar PV integration and makes several primary findings and recommendations:

- **The bulk power system can reliably manage over the five-minute time horizon the increase in net load variability associated with the solar PV and wind penetration levels studied (*i.e.*, up to 4,500 MW wind and 9,000 MW[2] solar PV).[3]** As the penetration levels of solar PV and wind increase, any projected increases in regulation requirements are relatively minor and can readily be accommodated within the current market rules, transmission system operations, and generation resource mix. As noted, this overall finding is contingent upon the current resource mix and its capability to provide regulation services. To the extent that there is significant turnover in the NYCA fleet, this capability may be reduced. It is, therefore, recommended that the NYISO continue to track solar PV and wind penetration levels and the capability of its generation fleet to provide such services in order to assess and make adjustments, as appropriate.

- **The large-scale implementation of behind-the-meter solar PV will impact the NYISO's load profile and associated system operations.** Although such impacts may be mitigated to a degree and at some future date by the implementation of on-site electric storage technologies, it is recommended that the NYISO take action now to incorporate in its control room operations and markets real-time and day-ahead forecasts of solar PV output as soon as practicable.

- **The lack of frequency and voltage ride-through requirements for solar PV facilities in New York could worsen system contingencies when solar PV deactivates in response to frequency and voltage excursions.** It is, therefore, recommended that the NYISO comment to the Federal Energy Regulatory Commission (FERC) and standard setting bodies, such as IEEE, in favor of industry standards for solar inverter systems requiring voltage and frequency ride-through capabilities. It is also recommended that the NYISO request that the New York Public Service Commission (NYPSC) and the New York Transmission Owners (NYTOs) consider establishing ride-through requirements on the non-bulk power system level.

- **The experience of other regions undergoing similar growth in intermittent energy resources confirms the importance of monitoring the NYCA's capability to serve its regulation and ramping needs as wind and solar PV penetration increases and displaces conventional thermal generation.** The rapid growth of intermittent resources in other regions has had material impacts on the availability of essential reliability services such as frequency, voltage and system inertia. It is, therefore, recommended that the NYISO continue to study future requirements and the availability

[2] All MW values for solar PV are denoted in DC capacity.
[3] The highest penetration values studied (*i.e.*, 9,000 MW of solar PV and 4,500 MW of wind) are not intended to reflect a ceiling for the integration of intermittent resources but are an achievable target in the next 5 to 15 years, assuming a reasonable amount of transmission can be built to interconnect the resources. Similarly, in its 2010 Wind Study the NYISO studied the impact on regulation requirements of up to 8,000 MW of wind which was considered to be the maximum achievable wind penetration within the time-frame studied.

of such services as the level of intermittent resources increases, while maintaining existing market incentives for resources to remain flexible to real-time market conditions.

This study did not address a number of important questions pertaining to the large-scale integration of renewable resources into the New York system, including: the extent to which transmission constraints on the local distribution and bulk power systems may require expansion to accommodate the levels of wind and solar PV studied; the extent to which conventional generating resources could meet the additional multi-hour ramping requirements; and to what extent conventional fossil fuel generation would be displaced by the wind and solar PV resources coming online.

This study lays the groundwork for additional research underway at the NYISO. Such research will examine, among other aspects of system operations, the impact of compliance with pending environmental regulations on essential reliability service capabilities: voltage support, frequency control, and ramping. Furthermore, the integration of higher levels of renewable resource naturally leads to the examination of the benefits from additional investments in new or expanded transmission facilities to collect and transport energy from areas with abundant renewable resources to New York load centers. Fulfilling the Western New York and AC Transmission Public Policy Transmission Needs identified by the New York Public Service Commission (NYPSC), currently under study through the NYISO's public policy transmission planning process, would add to the bulk power system's ability to move renewable resources to load centers within New York.

NYISO Solar Integration Study

1. Introduction

The establishment in 2012 and implementation of the NY-Sun Initiative (NY-Sun) is encouraging the development by 2024 of 3,000 MW[4] or more of behind-the-meter solar PV generation in the New York Control Area (NYCA). Significant increases in small- and large-scale behind-the-meter solar PV installations (approximating 570 MW as of May 2016) have already been experienced since the initiation of NY-Sun. The current installed base represents an increase from a total of 314 MW of installed solar electric statewide as of December 2014. These increases are supported not only by the NY-Sun incentives but also by the declining cost of installing solar PV systems, federal tax credits, and an expanding base of solar PV installation contractors. The heat map below (Figure 1-1) graphically depicts the distribution of behind-the-meter solar installations across the state as of December 2015.

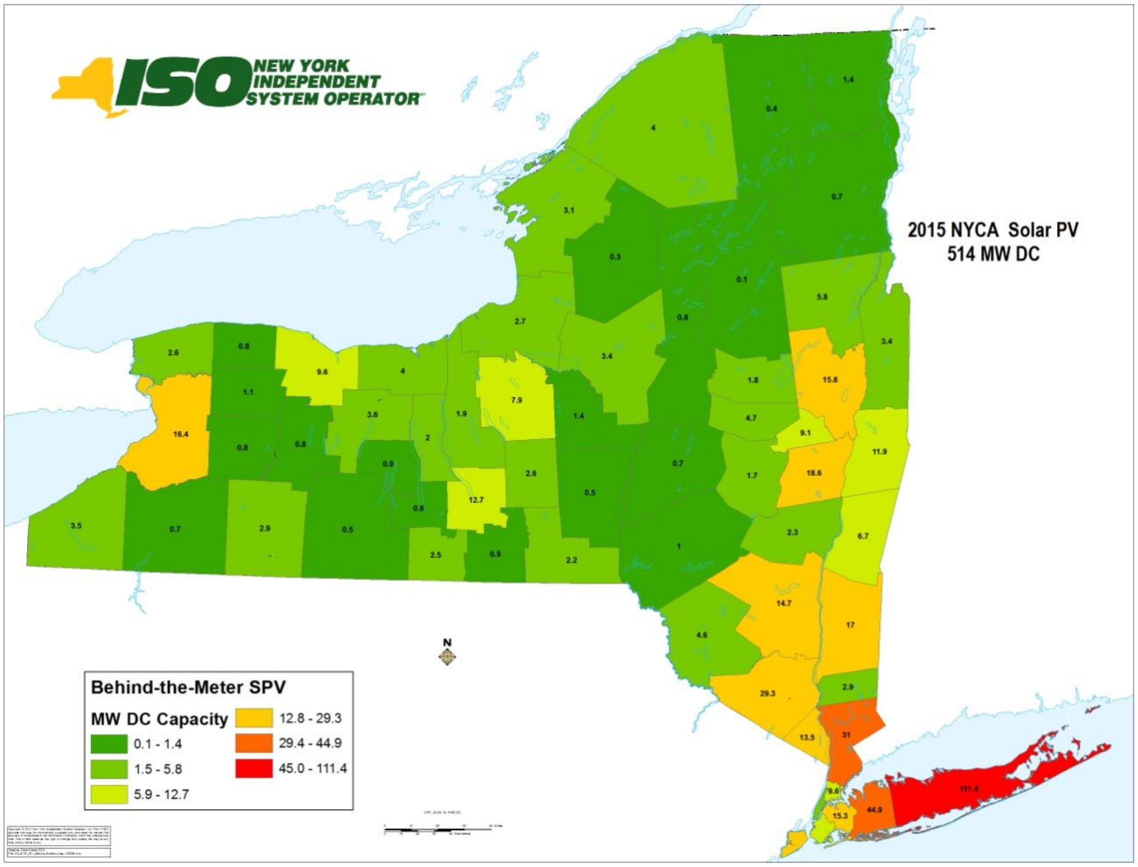

Figure 1-1: Heat Map of Behind-the-Meter Solar in 2015

[4] Unless noted, all MW values for solar PV are denoted in DC capacity.

Continuing efforts by state and federal government to encourage solar PV installations, coupled with continued reductions in the cost of solar panels and inverters, are expected to result in further, substantial increases in solar PV installations in New York during the years 2016–2030. The extension of the federal Solar Investment Tax Credit (ITC) in December 2015 will also serve to support the attainment of the NY-Sun program goals.

Solar PV generation output varies seasonally (*i.e.,* changing angle of the sun, length of daylight, and other factors), daily (*i.e.*, changing angle of the sun), and minute to minute (*i.e.*, changing cloud cover). Due to its intermittent nature, wide-scale installation and operation of solar PV generation can have significant impacts on power system operations. While the magnitude of the impacts may be relatively small at low solar PV penetration levels, new operating procedures may be required as penetration levels increase—particularly in combination with increased levels of wind generation. The potential impacts on reliable power system operation need to be fully understood to guarantee the reliable operation and planning of the New York Bulk Power System.

The NYISO conducted this study to investigate potential impacts of increased intermittent energy resources on the NYCA operations by focusing on four primary areas:

- development of hourly solar profiles and a 15-year solar PV projection by zone in the NYCA;
- a review of "lessons learned" and integration studies from other regions experiencing significant growth in solar and wind resources;
- an analysis of the impact of various levels of solar PV and wind penetration on NYCA's grid operating regulation requirements established based on the 2010 wind generation study; and
- a review of potential reliability concerns associated with the frequency and voltage ride-through characteristics of solar installations.

This study follows on the work of the NYISO's 2010 Wind Study, which concluded that the NYCA could reliably accommodate up to 8,000 MW of wind resources.

In this study the impacts on production costs, locational marginal prices, congestion costs, and uplift were not included in the scope of this study, nor did this study perform an economic evaluation of the costs and benefits of solar PV or wind generation.

The study analyzes and draws its conclusions on how the increased penetration of intermittent resources would impact NYCA system conditions using the current system resource mix and the best information currently available on the operating characteristics of solar and wind resources. Going forward, the increased penetration of emerging technologies (such as electric vehicles and electric storage) and advances in the efficiencies of intermittent resources, among other factors, may change the baseline conditions, which may affect how the studied build-out of large-scale renewable resources would impact system operations and, therefore, require this study to be revisited.

2. Study Tasks and Process

This study spanned a period of time from the spring of 2015 to the winter of 2016 and was conducted by NYISO Planning and Operations personnel. In order to accomplish the objectives of this study, the following tasks were identified and executed by the project team.

Task 1a: Prepare a 15-year projection of solar PV MW by zone. Develop hourly net-load shapes for various levels of solar PV penetration to illustrate the potential impact of solar PV installations on NYISO's ramping requirements.

Task 1b: Conduct an evaluation of potential solar forecasting vendors as a prelude to vendor selection and incorporation of solar MW and irradiance forecasts into the NYISO day-ahead and real-time commitment and dispatch operating procedures.

Task 2: Review the experiences and studies conducted for other regions of the U.S. and in Europe and consider the lessons learned in order to better plan and reliably operate intermittent generation in New York.

Task 3: Develop a simulated time series of five-minute load, solar PV, wind generation, and net loads for use in assessing potential impacts on NYCA regulation requirements at various levels of wind and solar PV penetration. In order to appropriately assess the current regulation requirements, which were established based on the 2010 wind generation study, the analysis considers six scenarios ranging from 1,500 MW of behind-the-meter solar PV installations to as much as 9,000 MW of behind-the-meter solar PV installations, and from 2,500 MW of wind generation to as much as 4,500 MW of wind generation, including the possibility of 1,000 MW of offshore wind, over the period 2019 to 2030.

Task 4: Perform a statistical analysis of the interaction of load and intermittent generation as measured by the net load to determine the potential impact of intermittent resources on regulation requirements.

Task 4a: Determine whether changes in intermittent generation would require adjustments to the NYCA regulation requirements from those levels established based on the 2010 wind generation study.

Task 4b: Perform a qualitative assessment of voltage and frequency ride-through effects and consider whether new standards for solar PV interconnections would be appropriate to prevent the creation of new bulk system reliability risks.

Task 5: Prepare a draft report to be reviewed with stakeholders for their information and comments, documenting the study process and results. Submit the final report to the NYISO Board.

3. Results for Task 1a- Solar Projection

3.1. Capacity Projection

Task 1a developed a solar PV projection by NYCA load zone through 2030. This projection relies heavily on the NY-Sun targets for solar PV in three regions: Long Island, New York City metropolitan area, and "Rest of State." It resulted in a projection with robust solar PV installations in the early and middle years, followed by a tapering off and leveling of installations by 2025. The use of an "adoption model" is consistent with the approach utilized by NYSERDA.

Table 3-1 presents the projected growth in total behind-the-meter solar PV installations by NYCA zone through 2030. For comparison purposes, the table also includes zonal distributions for projections of 4,500 MW, 6,000 MW, and 9,000 MW by 2030. The latter values were the scenarios studied as part of the regulation requirement evaluation in Task 4.

Table 3-1: Solar Capacity in 2030 by NYCA Zone

Scenario	Load Zone											NYCA
	A	B	C	D	E	F	G	H	I	J	K	
C3000	224	119	312	14	137	677	448	61	104	332	571	3,000
C4500	412	219	538	24	242	1,006	561	76	130	530	761	4,500
C6000	615	328	794	35	356	1,461	798	108	185	780	1,040	6,500
C9000	837	444	1,062	48	482	2,027	1,192	159	271	1,063	1,415	9,000

Figures 3-1 and 3-2 present the projected energy and peak load impacts of these installations.

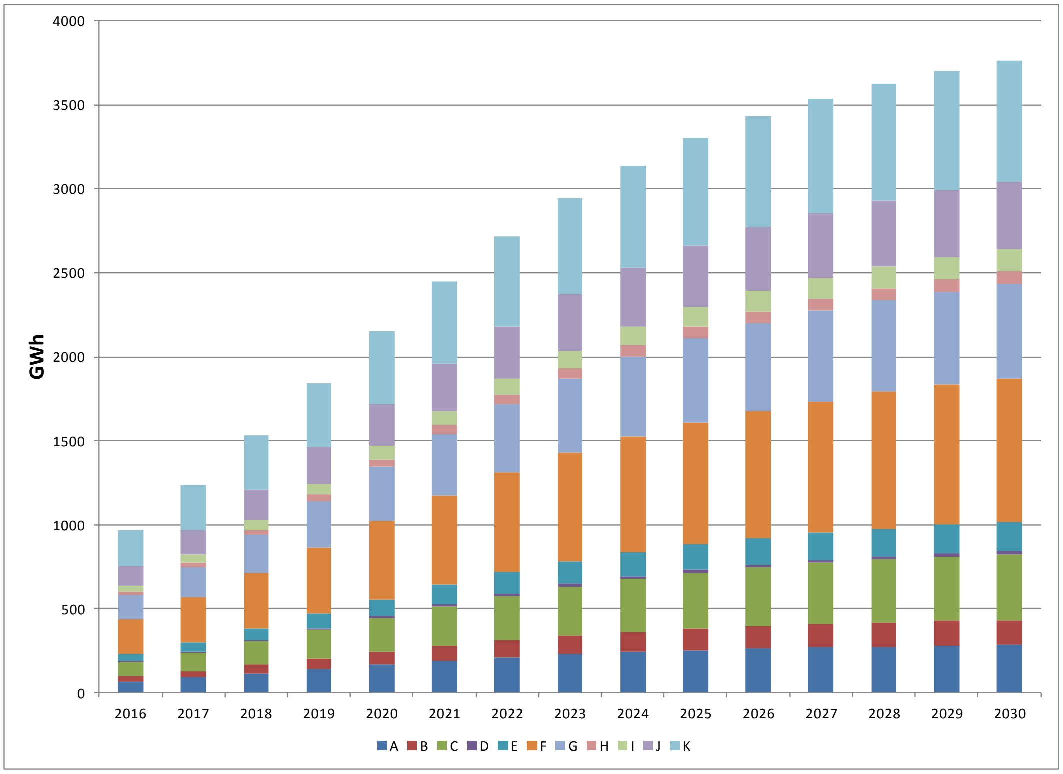

Figure 3-1: Energy Impacts by Year

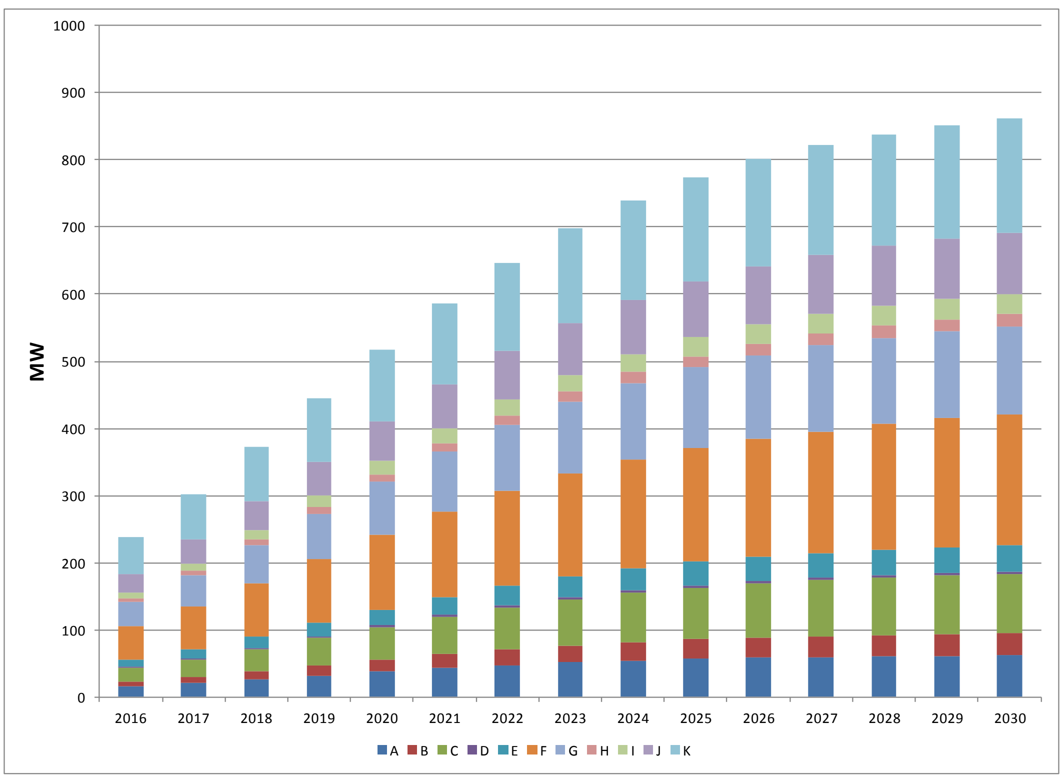

Figure 3-2: Peak Load Impacts by Year

The heat map in Figure 3-3 below presents the geographic distribution of the behind-the-meter installations incorporated in the 2030 aggregate solar PV forecast.

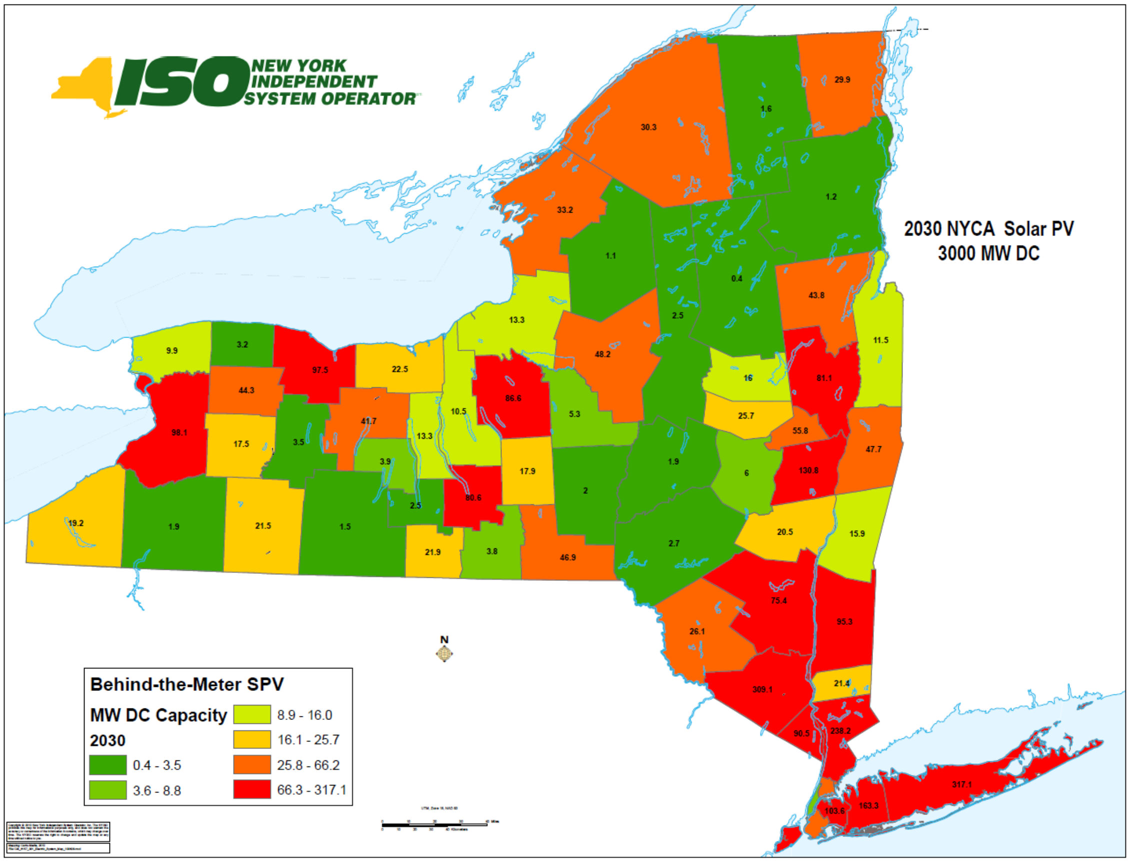

Figure 3-3: Heat Map of Behind-the-Meter Solar PV by 2030

3.2. Net Load Shapes

In order to study the impact of solar PV on typical system load conditions, hourly load shapes were developed utilizing, as a base, the existing load shape for 2007 (*i.e.*, a year classified as having normal weather conditions and, hence, load conditions that may be treated as having normal characteristics). For this analysis, the following data was collected:

- The 2007 Load Shape, and
- The typical solar PV impact shape obtained via NREL's PV Watts tool. This tool generates an 8,760 Hourly Load Shape for a specific location with a given system size and typical ambient conditions and technological parameters. Profiles of selected locations were weighted to proxy solar PV output for NYCA load zones, which were rolled up to yield a NYCA solar PV profile for a given capacity level. This was then netted against the calibrated 2007 Load Shape for the given year.

The following two charts present the impacts of various levels of solar penetration on a typical winter and summer day, illustrating the reductions in net-load and impacts on morning and evening ramps. The resulting shape of the curve, particularly noticeable in the winter shape, has been characterized as a "duck curve." These shapes can be considered as "business as usual" cases and do not consider the adoption of electric storage technologies or other measures (*i.e.*, load shifting) that could alter the current base load shape.

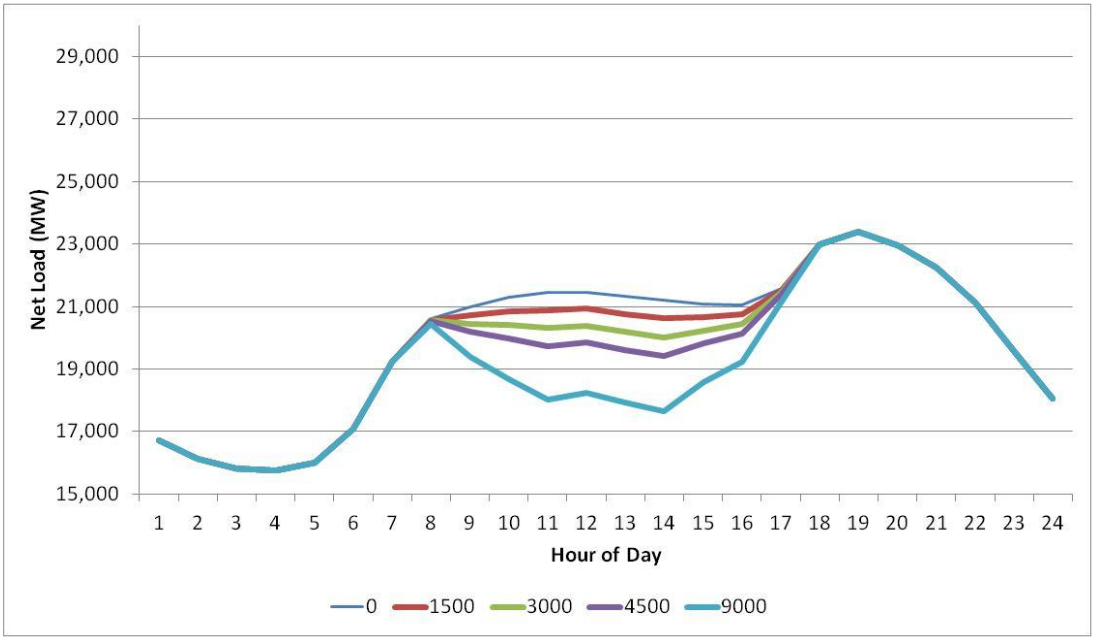

Figure 3-4: Typical Winter Day: Levels of Solar Penetration

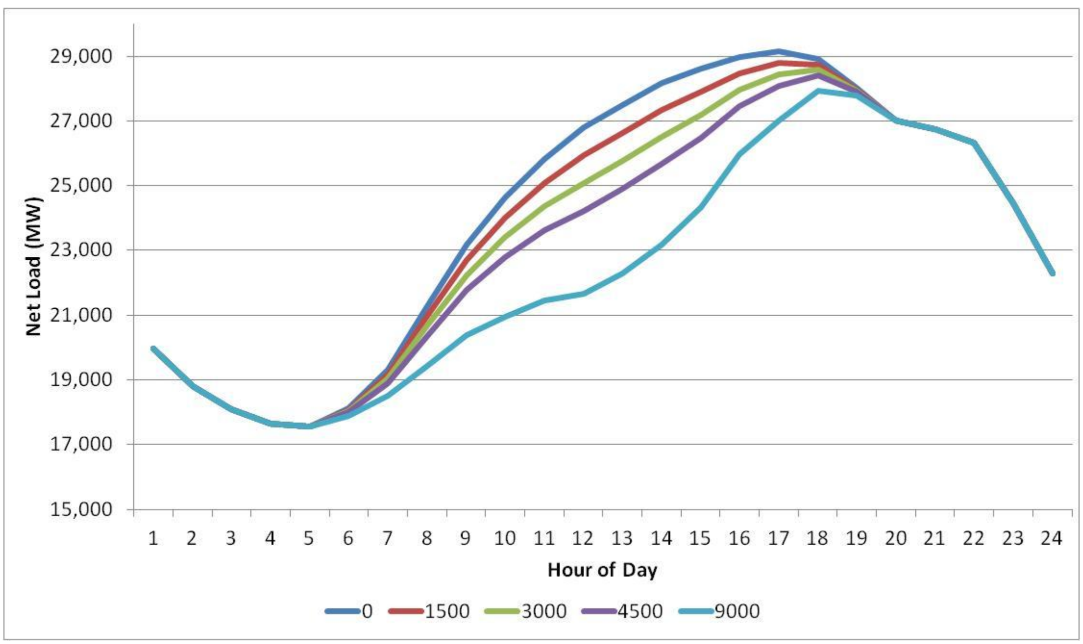

Figure 3-5: Typical Summer Day: Levels of Solar Penetration

4. Results for Task 1b – Solar Forecast Vendor

The NYISO conducted a six-month evaluation of the solar forecasting capabilities of three solar forecasting firms. The evaluation period ran from May 1, 2015 through October 31, 2015.

The field of solar forecasting for utilities and grid operators is relatively new, and there are a number of different approaches to developing irradiance and power forecasts. There are also differences in how distributed forecasts and site-specific forecasts are produced. The available methods include the use of numerical prediction models (similar to those currently used for weather forecasting), the use of satellite imagery, and the use of data which may be available from ground stations that may provide very recent measurements of irradiance.

Each proposed method had strengths and weaknesses, and it was not obvious by reading descriptions or reports whether one approach was clearly better than another. The knowledge, skill, and experience of forecasters were also factors, as was the ability to consistently delivery forecasts in a timely manner.

Each of the three contracted firms provided forecasts of solar irradiance (in watts per square meter) and the expected solar power (in MW) from both distributed solar resources and from large-scale solar power plants located at a given location. A set of forecasting metrics was developed by the NYISO to measure and assess forecast accuracy and bias. Specific forecast horizons were evaluated, such as 30, 60, 120, and 180 minutes ahead and one day ahead. These intervals are representative of both shorter-term and longer-term forecast horizons that are of interest for grid and market operations. The forecasts were updated each hour with the forecasts being provided at fifteen minute intervals for a three-day horizon. The hourly updates were integrated into the NYISO's load forecasting platform, which provided real-time display and served as a short-term archive of the data.

Once per week, summary statistics were developed and evaluated by NYISO staff and discussed with each vendor via web conferences. Forecasts were compared with measurements of irradiance from ground stations and from actual metered output of distributed and a specific large-scale solar PV installation. The weekly meetings allowed each firm to gradually adapt, adjust, and improve their forecasting methods and models over a period of time. This approach is also followed by other ISO/RTOs.

After the six-month period of data collection, a comprehensive analysis and review of results was performed based upon a standardized set of metrics that compared actual measured results to forecasts. These included over- and under-forecast error and frequency, the standard deviation of the errors, the r-square coefficient of actual versus forecast data, and other metrics. Forecast metrics were prepared on a monthly basis for each hour of the day for a selection of the forecast horizons. Metrics were prepared for both irradiance and power output. The results of the evaluation were used to select two firms to provide primary and backup solar irradiance and power forecasts. The figures below illustrate the type of data collected and evaluated.

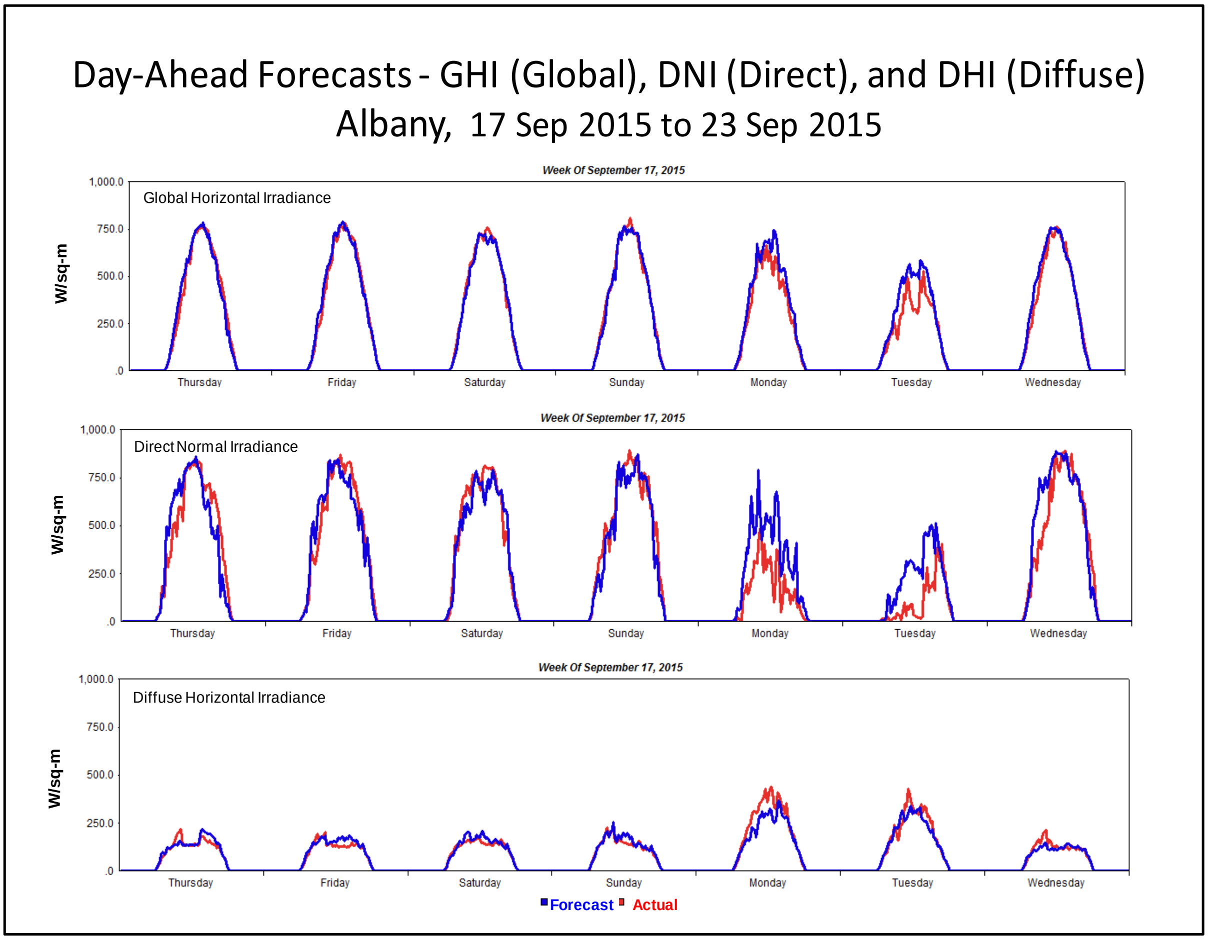

Figure 4-1: Forecasts of Irradiance During a Week in September

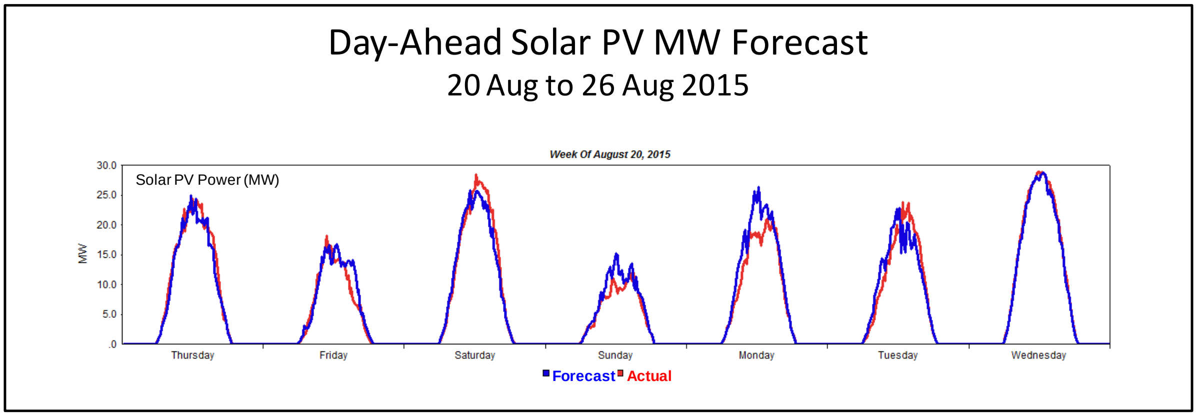

Figure 4-2: Forecasts of Solar Power During a Week in August

5. Results for Task 2 - Experience with Solar Integration in Other Regions

The purpose of Task 2 was to review the operating experience and studies performed for expansion of solar and wind plants in other regions of the U.S. and elsewhere in order to guide this study into areas of possible concern, or to suggest that the NYISO need not be overly concerned, about large amounts of intermittent energy resources. Although it is known that large amounts of behind-the-meter generation can pose operational problems at the distribution systems level, that is a matter best left to the individual transmission and distribution operator. The NYISO is responsible for reliably operating the bulk power system; therefore, this study was focused on matters that could affect the way in which generation is scheduled and dispatched for reliable operation.

Matters of potential concern included regulation requirements to adjust to short-term variations in output from intermittent generators, ramping requirements to match generation resources with the shape of the net load curve, and voltage and frequency ride through to protect the bulk power system during times of duress from the potentially exacerbating effects associated with the tripping of intermittent energy resources responding to low frequency or low voltage occurrences.

5.1. CALIFORNIA[5]

The California experience points to three broad challenges in the integration of solar and wind resources. These have been identified in studies and papers produced by both the California ISO (CAISO) and the California Energy Commission. The general conclusion is that, while California has been successful to date in managing electric system reliability, while driving towards achieving the 33% Renewable Portfolio Standard goal by 2020, there are key indicators that suggest additional actions are required to address potential system reliability issues. The first two of these relate directly to the impact of ever-increasing solar installations on the system load shape—the so-called "duck curve." While the morning and evening ramps maintain their historical patterns, mid-day loads are further and further suppressed. This results in significant over-generation in the mid-day period, as evidenced by the increased occurrence of negative energy prices since 2012. This in turn has led to increased curtailments of renewable resources in order to maintain the availability of fossil resources for the evening-ramp, requiring longer startup times. This impact is compounded by high levels of self-scheduled, fixed resources and interregional transactions.

The over-generation risk in the mid-day period is compounded by the need to ramp the system back up to meet the evening load, which is unaffected by the increased solar penetration. CAISO estimates that the ramp need in 2020 will be some 13,000 MW, approximately twice that required in 2012 due to the

[5] Sources for the California experience include: (a) *Impacts of Distributed Energy Generation on the State's Distribution and Transmission Grid*, California Public Utilities Commission, DNV GL Report No. 10007451-01, Rev. B, January 1, 2016; (b) "Briefing on the duck curve and current system conditions," California ISO, market Surveillance Committee Meeting, Clyde Loutan, July 15, 2015; and (c) California Energy Commission – Tracking Progress, http://www.energy.ca.gov/renewables/tracking_progress/documents/resource_flexibility.pdf.

forecasted growth in solar PV over this time period. The higher penetration of solar PV (or negative load) further lowers the mid-day loads and increases the distance between the load trough and load peak occurring in the early evening. The existing level of flexible resources in the system has been sufficient to manage the level of solar installations to date. However, the development of additional flexible resources will be required to enhance the reliable integration of additional renewable resources. The CAISO has indicated that the expansion of intermittent resources may entail: (i) the retrofit of existing power plants to enhance flexibility, (ii) enabling the economic dispatch of renewable (versus must-run), (iii) increased storage and demand response, (iv) targeted energy efficiency, and (v) deeper interregional coordination such as an expanded Energy Imbalance Market (EIM). Key attributes for these new flexible resources include: (1) fast ramping for defined periods, (2) the capability to change ramp direction quickly, (3) the capability to store energy or modify energy consumption, (4) the capability to start and stop frequently, and (5) a low minimum generation level. The CAISO is pursuing market rule changes at the FERC to implement a flexible ramping product.

This flexible ramping product is identified by CAISO as one of several new ancillary services under consideration to address the shorter-term variability and intermittency of renewable resources, specifically services for inertia, frequency response, and voltage support. The increased penetration of solar and wind resources drives an increasing need for these essential reliability services, which renewable resources are not currently able to provide. According to the California Public Utilities Commission (CPUC), conventional generation will therefore be required to fill the gap until newer technologies, such as smart inverters and controllable distributed loads, mature.

5.2. HAWAII[6]

There were four categories of conclusions from the 2013 solar integration study sponsored by Hawaiian Electric and performed by NREL, GE, and others. This study considered scenarios with renewables accounting for almost 75% of system peak load:

- High levels of renewables can be reliably accommodated by Hawaii's bulk power system, with changes to utility equipment, equipment for the intermittent generators, and operating practices,
- Intermittent generation needs to include inertial and frequency response, voltage and frequency ride through, ancillary services, and governor controls to respond to loss-of-load events,
- Variability is lower for a mix of solar and wind generation and is lower for distributed solar PV systems than for central station solar PV, and
- Distributed solar PV presents a challenge because of the inability to curtail power production.

GE's most recent study on Hawaii also identified the need for improved grid flexibility to accommodate the intermittency and variability of wind and solar generation. GE concluded that new operational

[6] Sources for the Hawaii experience, include: (a) *Hawaii Solar Integration Study*, National Renewable Energy Laboratory, Technical Report NREL/TP-5500-57215, June 2013; (b) *Hawaii Renewable Portfolio Standards Study*, Hawaii Natural Energy Institute , May 2015; and (c) "Overview and Status of Distributed Energy Resources Policy Docket," Hawaii Public Utilities Commission, Jay Griffin, August 4, 2015.

protocols and infrastructural upgrades would be required to address the increased variability of net load. Specific mention is made of lowering the minimum generation of thermal units, enhancing the capability of on-line generation to ramp up and down or cycle on and off daily, and additional ancillary services such as down-reserves (*i.e.*, the capability to specifically ramp down as directed) from wind and solar plants.

More recent reports from the Hawaii Public Utilities Commission also identify the following as technical integration challenges at a system level:

- Over-generation and increasing variability in generation resulting in the curtailment of renewable generation and frequency and ramping challenges for central station generation, and
- The behavior of the aggregated distributed energy resource fleet may amplify a system swing and lead to an unstable grid response during contingency events, which could damage equipment and cause power outages. To prevent this, it may be necessary to implement mandatory grid-supportive frequency and voltage trip and ride-through settings to help dampen swings and maintain stable system responses.

It should be noted that Hawaii has unit challenges because it consists of several small island systems with high solar penetration and, therefore, is not particularly comparable to New York in terms of system inter-ties or connectivity.

5.3. PJM[7]

PJM provided the final project review of its three-year renewable integration study in March 2014. The study's overarching conclusion was that, with adequate transmission expansion (up to $13.7 billion) and additional regulation reserves (up to an additional 1,500 MW), PJM would not have any significant reliability issues operating with up to 30% of its energy (as distinct from capacity) provided by wind and solar generation.

There were several additional findings, including:

- Additional regulation was required to compensate for the increased variability introduced by the renewable generation. The 30% scenarios, which added over 100,000 MW of renewable capacity, required an annual average of only 1,000 to 1,500 MW of additional regulation reserves compared to the roughly 1,200 MW of regulation reserves modeled for load alone,
- No additional operating (spinning) reserves were required,
- Cycling (start up, shut down) and ramping of existing thermal fleet increased, which would imply higher operating and maintenance (O & M) costs and unit emissions,

[7] Sources for the PJM experience, include: (a) *PJM Renewable Integration Study*, PJM Interconnection, LLC, November 2012; and (b) a fact sheet on electricity storage in PJM, https://www.pjm.com/~/media/about-pjm/newsroom/fact-sheets/electricity-storage.ashx.

- Capacity factors on thermal generation were reduced—more peaking units were economically dispatched to meet the afternoon ramp (rather than larger intermediate and base load generation running throughout the day), and
- PJM's large geographic footprint also provides significant benefit for integrating wind and solar generation because it greatly reduces the magnitude of variability-related challenges.

Study recommendations included:

- Dynamic procurement of regulation resources in the real-time based on short-term (1-2 hour ahead) wind and solar forecasts,
- Adoption of measures to improve real-time operations including short-term recommitment using a 4-hour ahead wind and solar forecast and improvements in accuracy of the day-ahead wind and solar forecast,
- Use of storage and demand resources for spinning reserves, and
- Re-evaluation of the ramping capabilities of existing thermal power plants.

PJM has highlighted energy storage (*e.g.*, lithium-ion batteries, flywheels, thermal storage devices and electric vehicles) as one means to address the intermittency of wind and solar resources. For example, a large battery facility, 32-MW AES Laurel Mountain in West Virginia, went into operation in 2011 in conjunction with a 98-MW wind farm. The battery facility is capable of changing its output in less than one second.

5.4. GERMANY[8]

Germany has so far managed to integrate and balance high shares of renewable energy with very modest changes to its power system. Its success has been attributed to the strength of its power grid and its ability to rely on the flexible operation of coal and nuclear plants (and to a lesser extent gas and pumped hydro). Outage statistics have remained flat or even decreased since 2007, during the period that saw a very rapid increase in power generation from intermittent renewable sources such as solar PV and wind. In its most recent Summer Outlook Report and Winter Review, the European Network of Transmission System Operators (ENTSO-E) reported that it saw no severe reliability issues in Germany's power grid. The report did acknowledge that under certain conditions (*e.g.*, summer, low demand, low levels of PV feed-in and moderate wind); Germany's power grid might experience voltage problems.

The report stated that to support the further development of renewable energy sources, it will also be necessary to further invest in transmission and distribution infrastructure. The former will primarily be required to transport wind (onshore and offshore) from generation in the north to load centers in south.

[8] Sources for the German experience, include: (a) *A Tale of Three Mar*kets, *Comparing the Solar and Wind Deployment Experiences of California, Texas and Germany*, Steyer-Taylor Center for Energy Policy and Finance (Stanford University), Mohrmann, Felix; Reicher, Dan and Hanna, Victor; (b) *Large-Scale Wind and Solar Integration in Germany*, US Department of Energy, PNNL-19225, February 2010; and (c) *Solar Energy Support in Germany, A Closer Look;* Solar Energy Industries Association, July 2014.

The report estimated the costs of required infrastructure investments in the high voltage transmission system at €16 billion.

5.5. ONTARIO, CANADA[9]

The Independent Electricity System Operator (IESO) reported that the changing supply mix is challenging its ability to effectively balance supply and demand. It specifically identified the continued need for flexible resources on the system to provide load following ramping and to manage the surplus base load generation.

There are three principal aspects to its solar integration efforts: forecasting, visibility, and dispatch.

- Forecasting: Ability to predict output from intermittent resources is essential for maintaining system reliability and market efficiency
- Visibility: New processes such as direct telemetry and reporting ensure visibility of large-scale embedded wind and solar generators
- Dispatch: Integration of renewables into the economic dispatch will address issues like surplus base load generation

The latter is critical to Ontario's capability to manage surplus base load generation (SBG), which stands as one of its primary technical impediments to integrating additional intermittent resources. Prior to the implementation of the ability to dispatch wind in 2013, SBG was managed through market mechanisms such as exports and nuclear unit redispatch. In 2013, the IESO also deployed a centralized forecasting system for wind and solar for facilities greater than 5 MW which was viewed as essential in reducing the uncertainty associated with the variability of solar generation.

5.6. Summary Remarks

In conclusion, the primary insights that can be drawn from the review of the other U.S. and European studies are as follows:

- There needs to be sufficient flexible resources in the system to manage the transformed net load patterns in order to meet the system's need for ramping and regulation services; such a resource mix can consist of existing and new technologies, including electric storage facilities such as battery storage, and
- Specific attention needs to be paid to the level of essential reliability services on the grid—inertia, frequency, and voltage support, and

[9] Source for the Ontario experience, include: "Integrating Renewable Generation: Ontario's Smart Grid Approach," Ontario Ministry of Energy, Ken Nakahara, presented at IEEE International Conference on Smart Energy Grid Engineering, August, 2013.

- Improvements in wind and solar forecasting should be prioritized to inform day-ahead and real-time system operations, and
- Planning for the large-scale integration of intermittent resources naturally leads to the consideration of the benefits of new or expanded transmission facilities in delivering renewable resources to load centers in New York State.

6. Results for Task 3 – Analyzing the Variability of Solar PV and Wind Output

In order to evaluate potential changes in its regulation requirements to address increased levels of intermittent resources in real-time operations, the NYISO obtained information on potential variability of system loads, wind power, and solar power. The changes in net load on the system were determined by subtracting wind and solar power from customer load. Wind data from 2006 at 5-minute intervals was previously obtained for the NYISO 2010 Wind Study.

These load shapes were subsequently utilized in the analysis of regulation requirements by evaluating the joint effect of wind and solar PV generation on the net NYCA load. For this purpose, 2006 load data was examined. The year 2006 was representative of extreme summer weather conditions with a higher than average number of high-load days with one day in which there was a minimal output from installed wind capacity and no solar PV. The following data was collected:

a) The existing 2006 load shape at 5-minute intervals,

b) The existing 2006 wind shape from AWS Truepower (a NYISO consultant on the integration of wind resources) at 5-minute intervals, and

c) The 2006 PV load shape, constructed from the 5-minute back-cast data for 10 km x 10 km cells across the state. This PV shape was developed as part of the Task 3 effort.

By netting (b) and (c) from (a), the NYISO obtained a net load shape at 5-minute intervals that was calibrated to match energy and peak conditions for the study scenarios.

Moreover, load and wind power data from 2006 was augmented with solar power production at 5-minute intervals representative of solar and sky conditions in the year 2006. The NYISO contracted with SUNY Albany to produce solar irradiance measurements based on satellite imagery of the Northeastern U.S. that was available at 30-minute intervals. A vector analysis was performed to determine how clouds were moving and, thus, to determine the spatial and geographic variations of solar irradiance. Results at 5-minute intervals for south facing surfaces inclined at 20 degrees from the horizontal were interpolated from the 30-minute interval data.

The NYISO utilized a geographic granularity of 10 km x 10 km rectangles, which resulted in about 4,100 in a single rectangle extending past the New York borders into Canada, Pennsylvania, and New England (Figure 6-1, red boundary). About 1,400 of these cells were contained within the boundaries of New York (Figure 6-1, blue boundary). Utilizing ARC-GIS mapping software, 831 cells out of the approximately 1,400 cells contained within the boundaries of New York were determined to currently have solar PV sites based on data available on websites maintained by NYSERDA. Cells located in waterways, forests, or other uninhabited areas were excluded from the data. Through this assumption, both spatial and temporal irradiance and MW variability measurements were obtained. The 831 cells were assigned to each of the 62 counties in the state, on average about 15 cells per county. Then the counties were assigned to each of the 11 NYISO load zones. Each county was assigned the 2015 installed capacity of behind-the-meter solar PV.

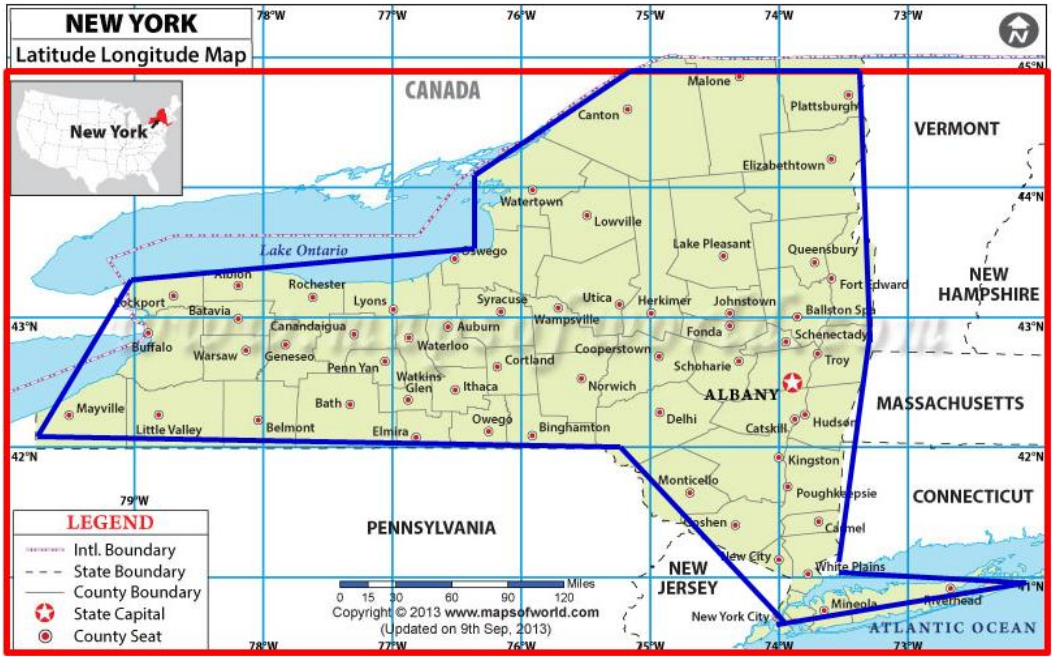

Figure 6-1: Rectangular Area for Which Solar Backcast for 2006 Was Obtained

The result is a spatial and temporal database representative of 2015 solar PV resources in the state, which can be aggregated to the zonal level or the NYCA level. For the purpose of evaluating regulation requirements in Task 4, the county-level data was summed to obtain a statewide estimate of solar PV. The installed capacity was varied to represent each of the several "renewable penetration" scenarios examined in Task 4.

Based on the temporal aspect of the irradiance and the satellite data, measures of irradiance (in watts per square meter) were obtained at 5-minute intervals for each of the aforementioned cells. The irradiance was converted to MW (AC) for a given level of installed capacity at any given level of geographic size. As an example, the chart below shows the output from solar PV resources in MW (AC) that is representative of a 7-day period in New York at 5-minute intervals at a solar installation level of 1,500 MW. Also included are total load and net load (*i.e.*, load less solar PV).

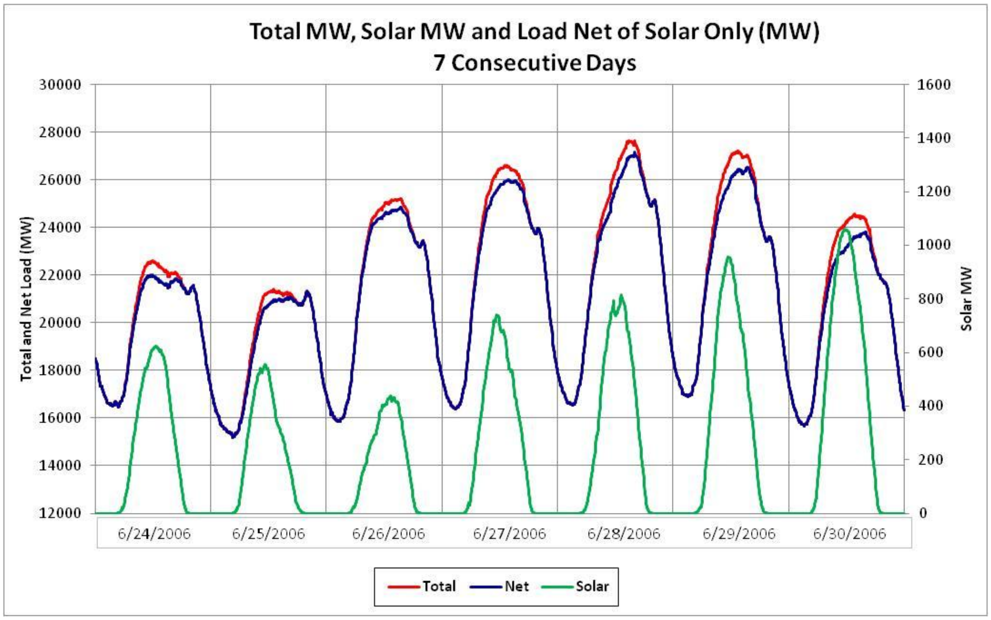

Figure 6-2: Solar PV, Total Load and Net Load for a 7-day Period

As presented in Table 6-1, three study scenarios of statewide solar potential were selected as follows: (1) 1,500 MW solar PV plus 2,500 MW wind for the year 2019; (2) 3,000 MW solar PV plus 3,500 MW wind for the year 2024; and (3) either 4,500 MW or 9,000 MW solar PV plus either 4,500 MW wind (either all on-shore or 3,500 MW on-shore plus 1,000 MW off-shore) for the year 2030. For each such level, the total installed MW AC capacity was distributed by time and space according to the projections of solar and wind installations in each of the load zones. These results were then delivered to NYISO staff for use in Task 4, Assessing Regulation Requirements.

Table 6-1: Scenarios for Regulation Study

Scenario	Year	Projected Summer Peak Load (MW)	Projected Wind Penetration (MW)		Projected Solar Penetration (MW)
			On-Shore	Off-Shore	
1	2019	34,600	2,500	0	1,500
2	2024	35,800	3,500	0	3,000
3A	2030	37,000	4,500	0	4,500
3B	2030	37,000	3,500	1,000	4,500
3C	2030	37,000	4,500	0	9,000
3D	2030	37,000	3,500	1,000	9,000

7. Results for Task 4 - Assessing Regulation Requirements

The focus of Task 4 was to study the impacts on system operations of the installation of wind and behind-the-meter solar resources above current levels in three scenarios at various levels of penetration, ranging up to 9,000 MW of solar and 4,500 MW of wind. While discrete levels of solar PV and wind penetration were studied, the NYISO's approach to establishing regulation requirements is based on ranges between the specific MW levels. For example, the current regulation requirements (which approximate those in Scenario 1) would remain in place until the Scenario 1 wind or solar PV levels are exceeded. Similarly, as the Scenario 2 wind or solar PV levels are exceeded, the regulation requirements identified in Scenario 3 would be considered for adoption as requirements by NYISO system operations.

The range for each scenario is as follows:

Table 7-1: Scenario Details

Scenario	Wind		Solar	
	Minimum	Maximum	Minimum	Maximum
1	Current	2,500	Current	1,500
2	2,500	3,500	1,500	3,000
3a	3,500	4,500	3,000	4,500
3b	3,500	4,500	3,000	4,500
3c	3,500	4,500	4,500	9,000
3d	3,500	4,500	4,500	9,000

The NYISO evaluated the impacts of significantly increasing the penetration of intermittent resources, specifically, on bulk power system regulation requirements. As described above, system regulation allows the power system to respond to the variability of net load that may occur over a 5-minute dispatch interval to maintain the simultaneous balance of resources and load in operations.

The focus of this analysis is on the variability of net load in the five- to ten-minute time horizon and how much regulation is required to maintain reliable system operations. In 2010, the NYISO performed an evaluation of the impact of wind resources on net load due to the intermittency and limited controllability of the wind resources. Solar PV resources are equally intermittent and cyclical and are projected to be predominantly distributed (*i.e.*, behind-the-meter) with little visibility to system operators and with even less ability to dispatch. Although the evolution of smart systems may address the visibility issue and provide more situational awareness, the expectation is that system operators in the near term may only be able to track the real-time fluctuations in distributed solar output by observing changes in the load on the bulk power system.

The approach to calculating regulation requirements mirrors that utilized in the 2010 wind generation study with the addition that variability in solar PV generation is now captured as well. It was determined that the solar variability would be treated identically to that of wind to reflect 10 minutes of variability using a persistence assumption for forecasting the next interval's generation level. Variability is measured by changes in the 5-minute net load and solar and wind generation, as follows:

$$\text{Net Load}_{t} = \text{Base Load}_{t} - \text{Wind Gen}_{t} - \text{Solar Gen}_{t}$$

$$\text{Net Load}_{t\text{-}5} = \text{Base Load}_{t\text{-}5} - \text{Wind Gen}_{t\text{-}10} - \text{Solar Gen}_{t\text{-}10}$$

$$\text{Net Load Delta}_{t} = \text{Net Load}_{t} - \text{Net Load}_{t\text{-}5}$$

Figure 7-1: Net Load Variability Calculations

The standard deviation (or sigma) of the Net Load Delta is then utilized to indicate the fluctuation in the net load from period to period. For each hour the net-load variability corresponding to a 3-sigma level (incorporating 99.7% of the sample set, based on a normal distribution) was calculated. The resulting 3-sigma value represents the amount of regulation resources required to manage the net-load variability.

As part of the validation of the results, four adjustments were made to the raw study results as follows:

- Regulation requirements were set in 25 MW increments;
- The hour-to-hour change in regulation was limited to 50 MW to minimize unnecessary real-time energy pricing volatility;
- For all hours with a decrease in the requirement, a validation against the historical CPS2 performance in 2013/2014 was considered to ensure continued compliance; and
- The hourly change from one scenario or penetration level to the next was limited to a maximum of 75 MW and a minimum of 0 MW.

7.1. Current Regulation Requirements

The NYISO established its current regulation requirements based on the 2010 wind generation study. These requirements are seasonal and reflect net-load variability, accounting for fluctuations in load demands and wind generation. Current regulation requirements are posted on the NYISO website:[10]

Table 7-2: Current Regulation Requirements (MWs)

Hour Beginning	April - May	June - August	September - October	November - March
0	175	225	175	200
1	175	175	175	175
2	175	175	150	175
3	175	175	175	150
4	225	225	225	175
5	225	250	275	225
6	225	275	275	275
7	200	275	250	275
8	200	275	225	275
9	175	225	200	225
10	200	225	175	175
11	200	250	200	175
12	175	225	200	175
13	175	225	200	175
14	175	250	175	175
15	175	225	175	225
16	175	250	200	275
17	200	250	250	300
18	225	250	275	250
29	250	250	250	250
20	200	250	250	200
21	200	250	250	225
22	200	275	200	200
23	200	275	225	200

7.2. Scenario 1

Results from Scenario 1 (2,500 MW wind and 1,500 MW solar PV) confirm that the current regulation requirements are appropriate, given the limited experience with large-scale distributed solar PV and bulk-connected solar PV installations. It is expected that the current regulation will remain in place until the penetration of solar PV surpasses the 1,500 MW level. Note that regulation requirements are

[10] http://www.nyiso.com/public/webdocs/market_data/reports_info/nyiso_regulation_req_sum04.pdf.

established by season—April–May (Spring), June–August (Summer), September–October (Fall), and November–March (Winter). Tables 7-2, 7-3, 7-4, and 7-5 present a comparison of the raw 3-sigma results, by season and by hour, for Scenario 1. All hours are in Eastern Standard Time.

Table 7-3: Scenario 1 Winter Regulation Results (MWs)

Winter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	170	122	98	93	103	188	256	206	153	133	122	113	132	118	104	114	242	251	230	120	133	157	160	167
3σ Load - Wind Only	203	180	150	143	144	205	274	224	177	162	146	142	173	163	165	157	259	258	239	153	158	175	189	186
3σ Load - Solar Only	170	122	98	93	103	188	256	212	174	149	129	122	138	129	111	122	210	251	229	120	133	157	160	167
3σ Load - (Wind & Solar)	203	180	150	143	144	205	274	230	195	175	151	146	181	171	172	165	231	259	239	153	158	175	189	186
2010: 2006 Results	189	143	160	142	135	201	287	256	211	180	161	153	143	152	166	156	234	294	254	183	198	197	186	188
Current Prod. Values	200	175	175	150	175	225	275	275	275	225	175	175	175	175	175	225	275	300	250	250	200	225	200	200

Table 7-4: Scenario 1 Summer Regulation Results (MWs)

Summer	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	125	101	97	100	165	222	176	133	136	127	119	125	110	104	105	106	122	154	192	174	168	162	157	150
3σ Load - Wind Only	179	168	174	169	208	251	202	176	177	164	147	158	174	141	135	151	165	218	219	228	203	250	210	188
3σ Load - Solar Only	125	101	97	100	163	218	175	135	137	124	120	127	115	110	112	109	124	148	172	173	168	162	157	150
3σ Load - (Wind & Solar)	179	168	174	169	208	249	202	173	179	159	144	158	176	144	143	157	167	217	201	225	203	250	210	188
2010: 2006 Results	173	152	164	167	193	208	187	198	168	157	178	181	215	221	202	181	259	231	217	258	216	226	233	216
Current Prod. Values	225	175	175	175	225	250	275	275	275	225	225	250	225	225	250	225	250	250	250	250	250	250	275	275

Table 7-5: Scenario 1 Spring Regulation Results (MWs)

Spring	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	116	95	91	119	171	230	179	152	132	118	113	106	112	109	101	103	115	144	204	221	160	158	140	140
3σ Load - Wind Only	177	161	141	159	193	252	204	182	152	150	141	150	165	142	153	143	158	185	226	233	197	190	188	177
3σ Load - Solar Only	116	95	91	119	171	229	187	153	132	116	114	115	121	115	115	110	119	144	190	221	160	158	140	140
3σ Load - (Wind & Solar)	177	161	141	159	193	253	210	182	153	151	144	162	174	150	165	144	161	183	214	233	197	190	188	177
2010: 2006 Results	161	144	131	129	204	249	183	208	160	181	158	174	186	199	181	195	191	203	235	246	211	203	175	175
Current Prod. Values	175	175	175	175	225	225	225	200	200	175	200	200	175	175	175	175	175	200	225	250	200	200	200	200

Table 7-6: Scenario 1 Fall Regulation Results (MWs)

Fall	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	104	93	83	102	179	267	189	126	125	132	105	96	85	87	83	94	126	211	181	135	133	132	136	125
3σ Load - Wind Only	175	165	139	135	202	291	213	160	150	159	133	132	169	157	133	138	158	231	229	181	167	176	166	163
3σ Load - Solar Only	104	93	83	102	179	268	201	152	128	137	107	101	98	98	97	95	116	201	180	135	133	132	136	125
3σ Load - (Wind & Solar)	175	165	139	135	202	292	224	185	150	166	134	134	186	171	150	137	150	220	228	181	167	176	166	163
2010: 2006 Results	149	151	133	145	206	271	203	200	178	159	154	156	179	177	164	162	172	251	214	196	199	193	164	172
Current Prod. Values	175	175	150	175	225	275	275	250	225	200	175	200	200	200	175	175	200	250	275	250	250	250	200	225

The following figures present the data graphically.

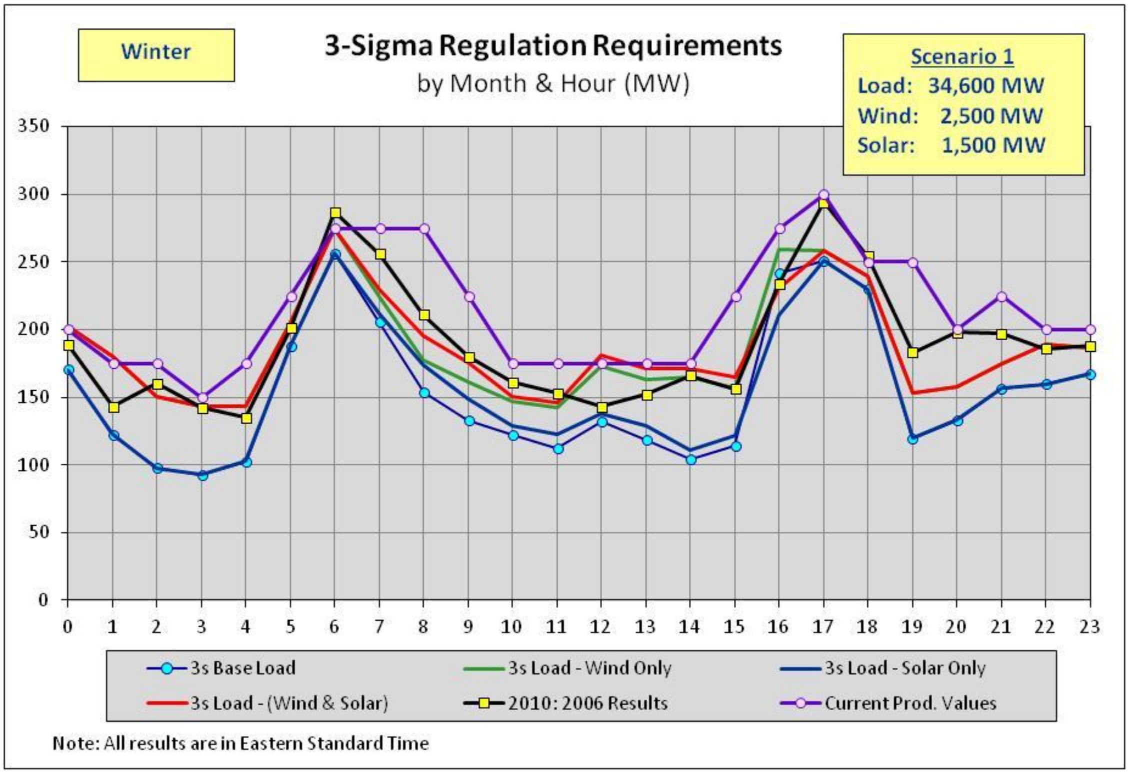

Figure 7-2: Scenario 1 Winter Regulation Results

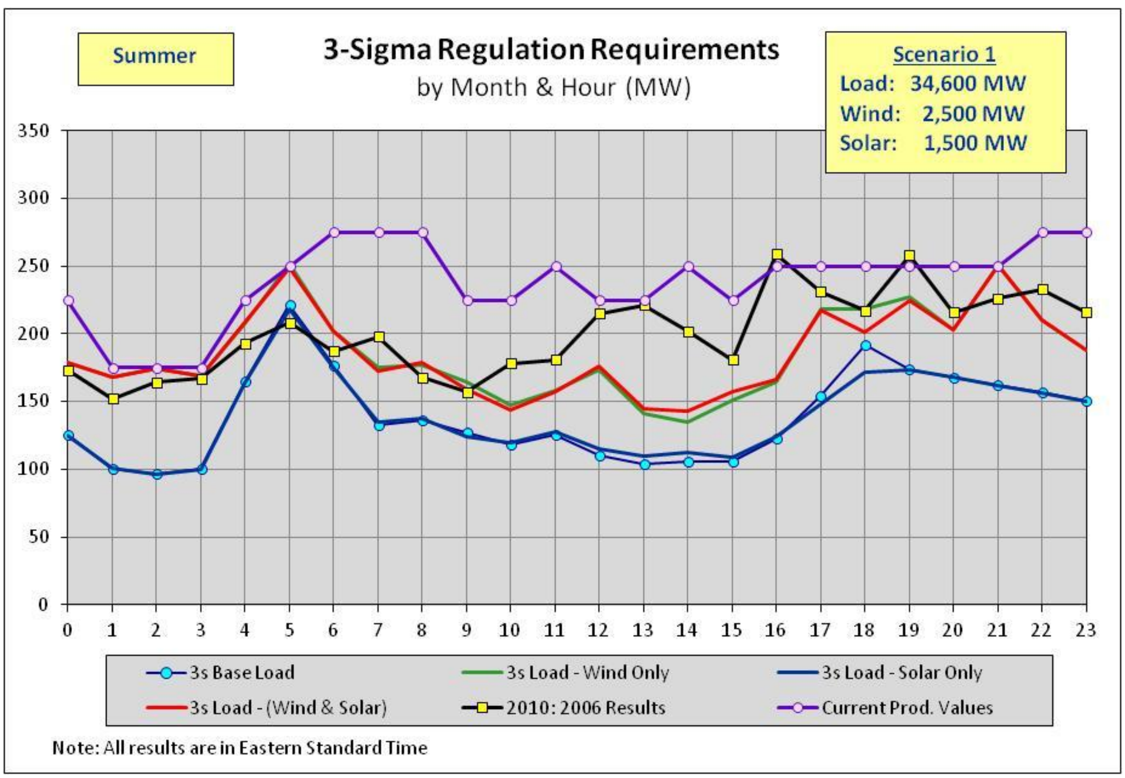

Figure 7-3: Scenario 1 Summer Regulation Results

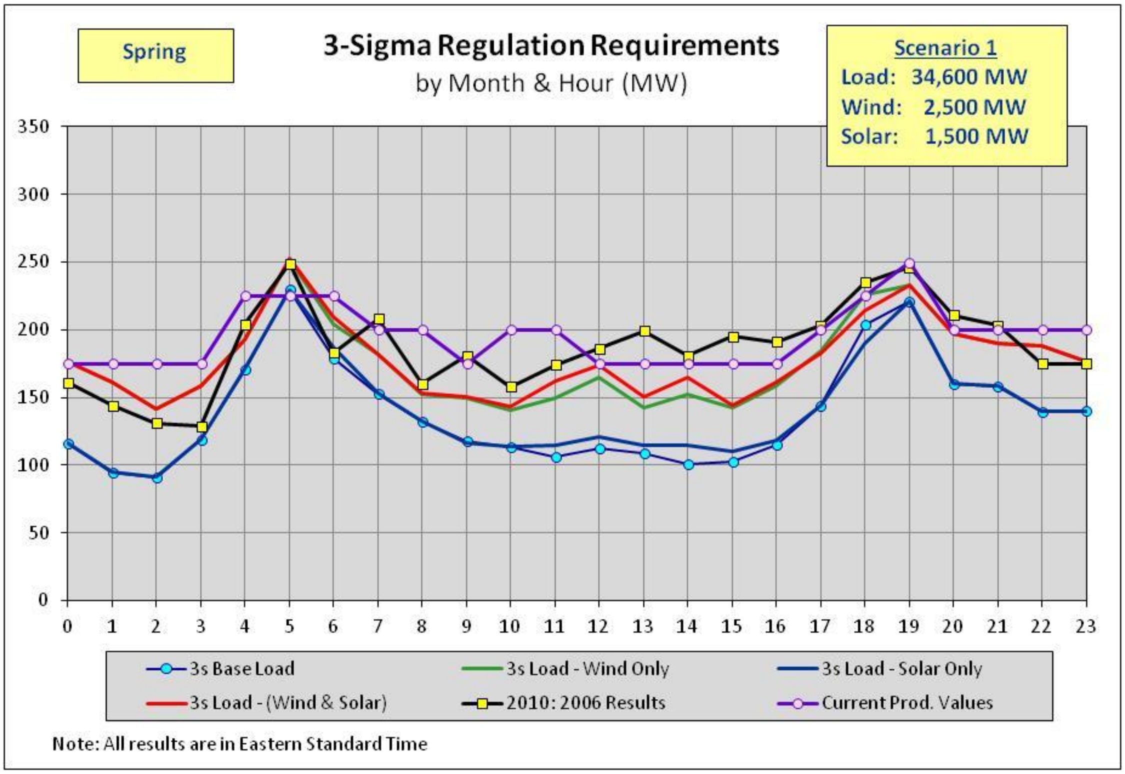

Figure 7-4: Scenario 1 Spring Regulation Results

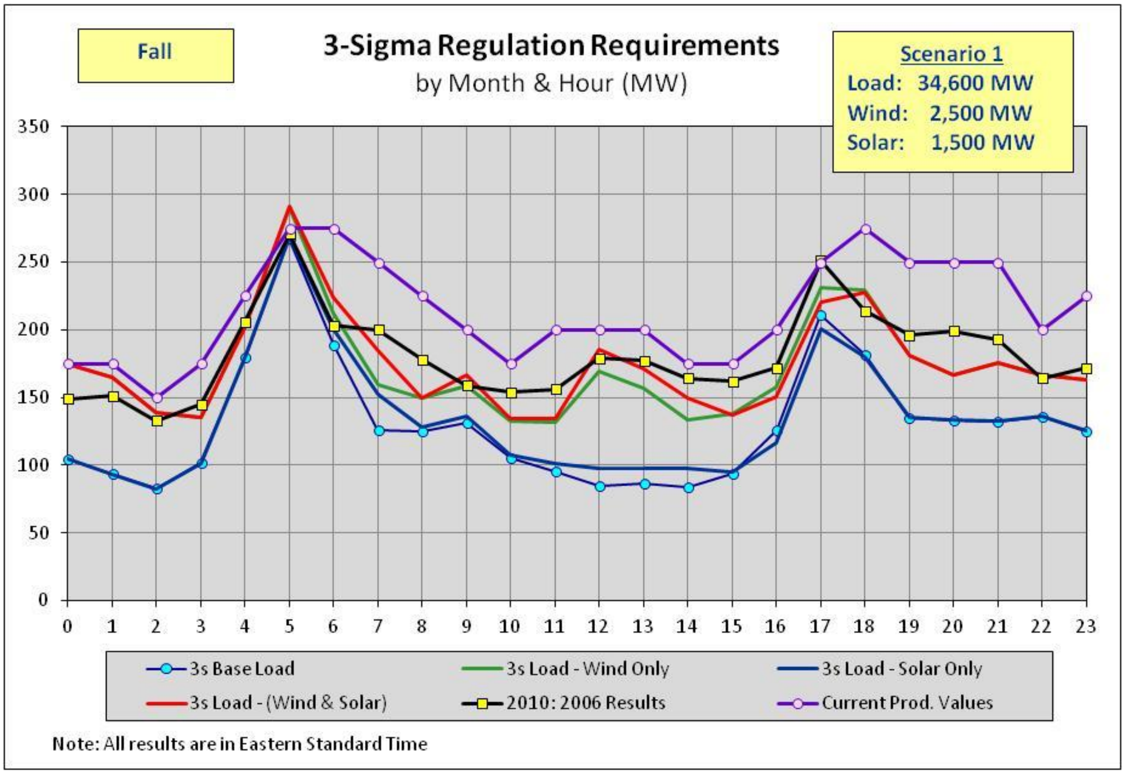

Figure 7-5: Scenario 1 Fall Regulation Results

7.3. Scenario 2

Results from Scenario 2 (3,500 MW wind and 3,000 MW solar PV) indicate that as the integration of intermittent resources on the system surpasses 1,500 MW of solar PV, slight changes in the system's regulation requirements may exceed the current production levels, which implies that minor upward revisions of the regulation requirements could be warranted. Tables 7-6, 7-7, 7-8, and 7-9 present a comparison of the raw 3-sigma results for Scenario 2 by season and by hour. All hours are in Eastern Standard Time.

Table 7-7: Scenario 2 Winter Regulation Results (MWs)

Winter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	176	127	101	96	106	195	265	213	159	138	127	116	137	122	108	118	251	260	238	124	138	162	165	173
3σ Load - Wind Only	234	230	189	180	178	228	296	246	200	186	169	169	215	200	207	192	283	276	266	191	182	199	217	214
3σ Load - Solar Only	176	127	101	96	106	195	265	236	243	180	149	151	156	157	137	167	199	261	237	124	138	162	165	173
3σ Load - (Wind & Solar)	234	230	189	180	178	228	297	269	262	220	186	187	238	223	225	226	241	277	266	191	182	199	217	214
2010: 2006 Results	189	143	160	142	135	201	287	256	211	180	161	153	143	152	166	156	234	294	254	183	198	197	186	188
Current Prod. Values	200	175	175	150	175	225	275	275	275	225	175	175	175	175	175	225	275	300	250	250	200	225	200	200

Table 7-8: Scenario 2 Summer Regulation Results (MWs)

Summer	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	129	104	100	104	170	229	182	137	141	132	123	130	114	107	109	109	127	159	199	180	174	168	162	155
3σ Load - Wind Only	223	217	224	219	254	282	230	208	209	193	176	182	214	170	160	186	199	271	258	271	240	307	254	223
3σ Load - Solar Only	129	104	100	104	168	225	201	147	150	135	130	145	135	138	139	127	141	153	165	179	174	168	162	155
3σ Load - (Wind & Solar)	223	217	224	219	254	279	233	209	216	187	175	192	222	184	182	206	207	273	250	266	240	307	254	223
2010: 2006 Results	173	152	164	167	193	208	187	198	168	157	178	181	215	221	202	181	259	231	217	258	216	226	233	216
Current Prod. Values	225	175	175	175	225	250	275	275	275	225	225	250	225	225	250	225	250	250	250	250	250	250	275	275

Table 7-9: Scenario 2 Spring Regulation Results (MWs)

Spring	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	120	98	94	123	177	238	185	158	137	122	117	110	116	112	104	106	119	149	211	229	166	164	144	145
3σ Load - Wind Only	222	211	176	193	220	280	229	209	172	177	167	183	200	170	190	175	194	222	251	253	231	221	228	207
3σ Load - Solar Only	120	98	94	123	177	238	216	166	154	142	130	137	145	136	144	133	132	153	188	229	166	164	144	145
3σ Load - (Wind & Solar)	222	211	176	193	220	284	258	212	183	193	180	214	224	194	220	183	203	220	233	253	231	221	228	207
2010: 2006 Results	161	144	131	129	204	249	183	208	160	181	158	174	186	199	181	195	191	203	235	246	211	203	175	175
Current Prod. Values	175	175	175	175	225	225	225	200	200	175	200	200	175	175	175	175	175	200	225	250	200	200	200	200

Table 7-10: Scenario 2 Fall Regulation Results (MWs)

Fall	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	108	96	86	105	185	277	195	130	129	136	109	99	88	90	86	97	130	218	188	140	138	137	141	129
3σ Load - Wind Only	224	221	185	167	227	317	240	191	175	185	157	158	218	205	171	170	188	272	267	215	198	219	202	195
3σ Load - Solar Only	108	96	86	105	185	279	225	220	148	157	124	121	129	124	129	115	141	202	185	140	138	137	141	129
3σ Load - (Wind & Solar)	224	221	185	167	227	319	266	255	190	208	167	170	257	239	211	174	195	241	264	215	198	219	202	195
2010: 2006 Results	149	151	133	145	206	271	203	200	178	159	154	156	179	177	164	162	172	251	214	196	199	193	164	172
Current Prod. Values	175	175	150	175	225	275	275	250	225	200	175	200	200	200	175	175	200	250	275	250	250	250	200	225

The following figures present the data graphically.

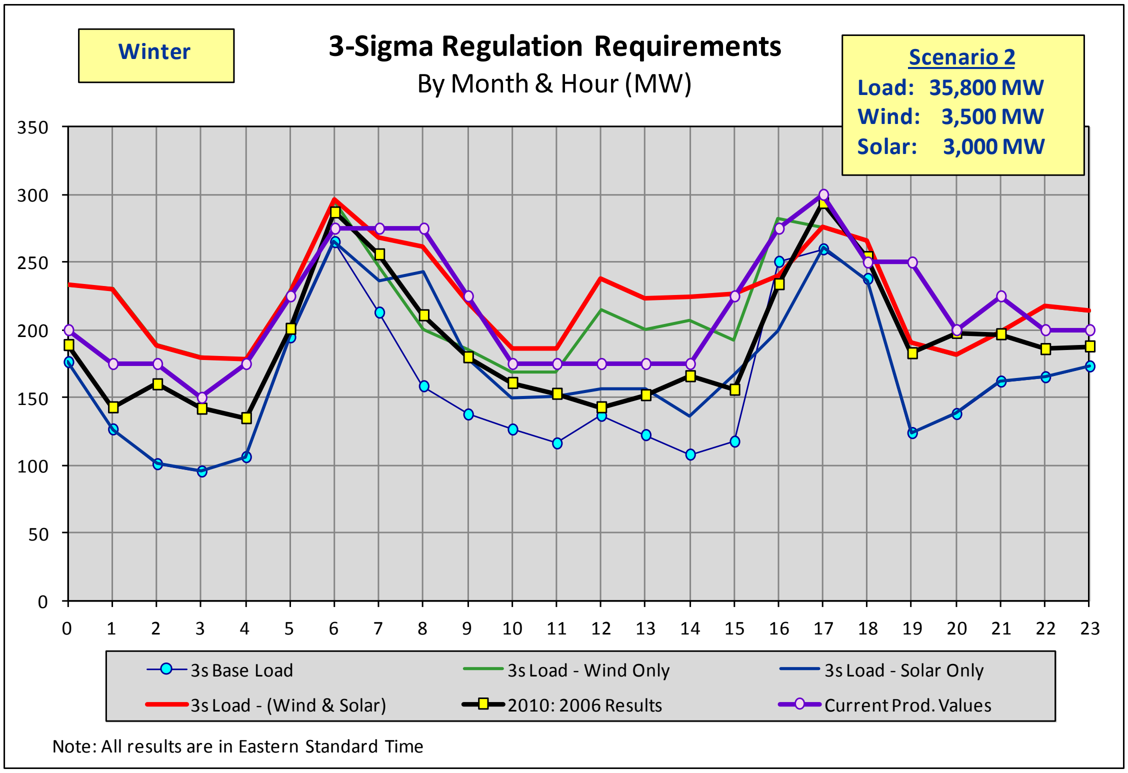

Figure 7-6: Scenario 2 Winter Regulation Results

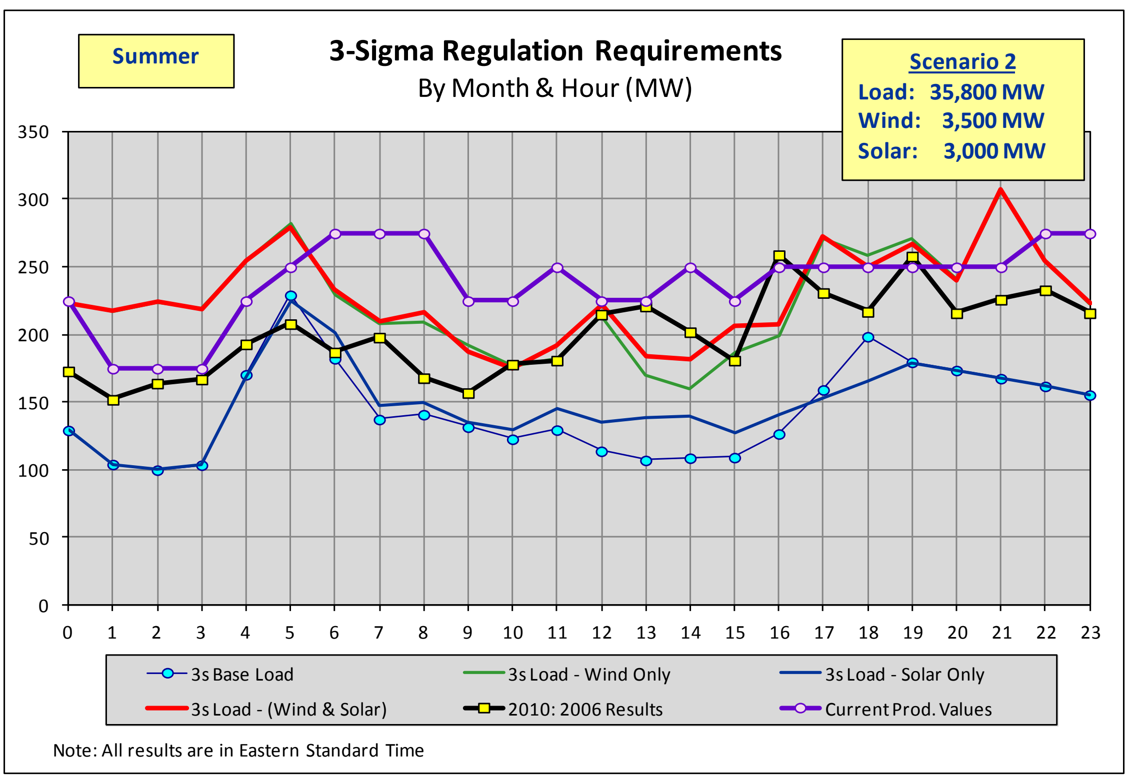

Figure 7-7: Scenario 2 Summer Regulation Results

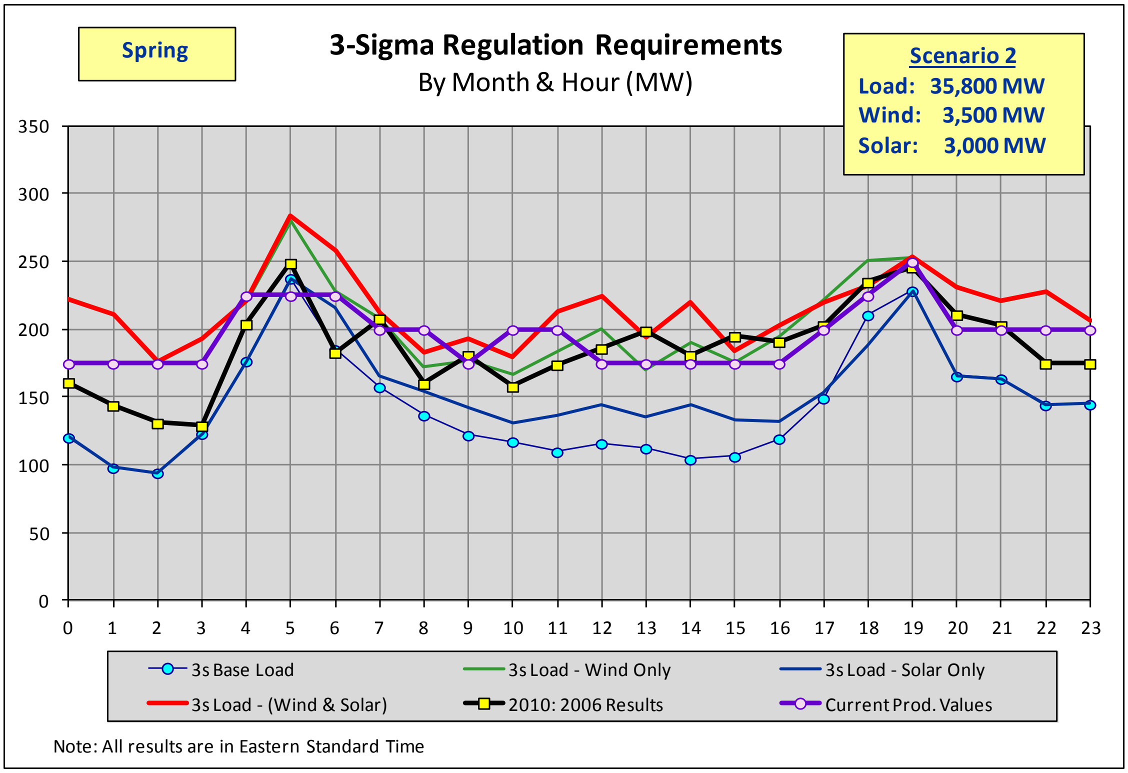

Figure 7-8: Scenario 2 Spring Regulation Results

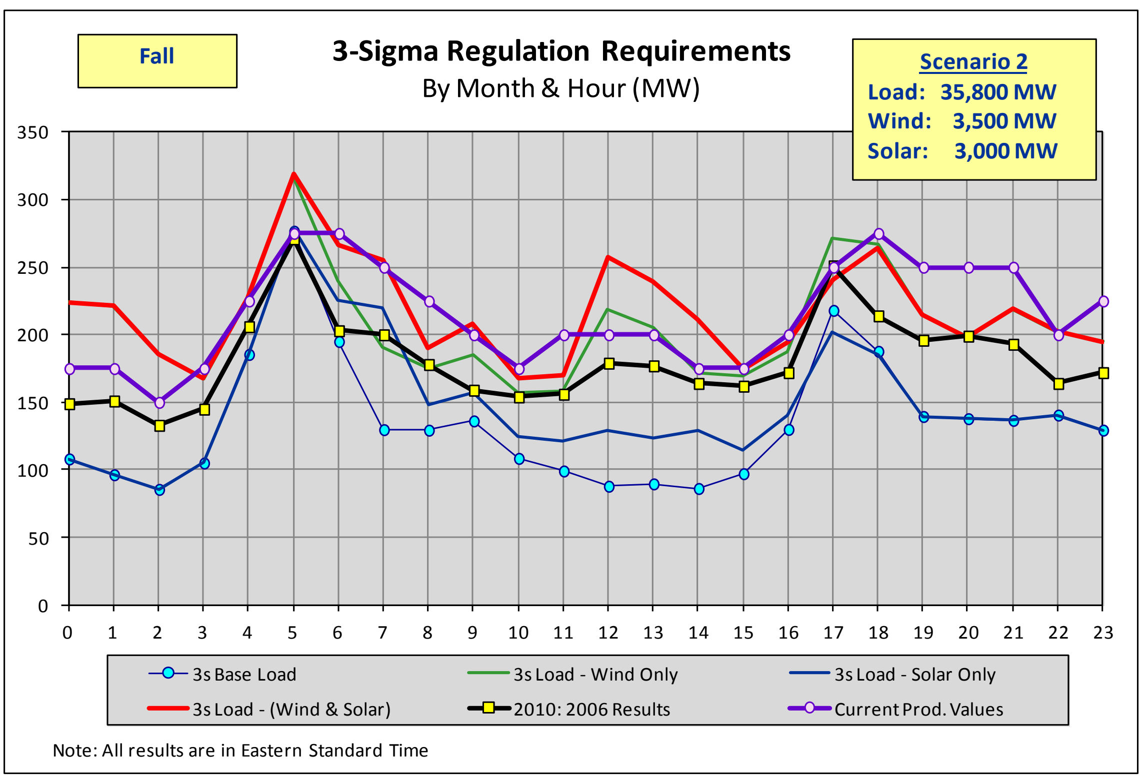

Figure 7-9: Scenario 2 Fall Regulation Results

The results of Scenario 2 were further analyzed by NYISO Operations to translate the raw results into projected regulation requirements. Tables 7-11 and 7-12 present these results, which indicate the need for minor increases in regulation requirements in 29 of the 96 hourly periods, while potentially allowing for decreases in minimum levels needed in 4 hourly periods, with an overall average increase of 10 MW across all hours. In Table 7-11, the green cells indicate the hours in which the levels of resource penetration yield a potential increase in the requirement, while the yellow cells indicate the hours in which the levels of resource penetration yield a potential decrease in the minimum regulation requirement. In Table 7-12, the varying shades of blue and red cells indicate the relative size of the increase or decrease of regulation requirements in each hour.

Table 7-11: Projected Regulation Requirements (MWs)

Hour Beginning	April - May		June - August		September - October		November - March	
	Current Requirement	2024 3,500 MW Wind 3,000 MW Solar	Current Requirement	2024 3,500 MW Wind 3,000 MW Solar	Current Requirement	2024 3,500 MW Wind 3,000 MW Solar	Current Requirement	2024 3,500 MW Wind 3,000 MW Solar
0	175	175	225	225	175	175	200	200
1	175	175	175	175	175	175	175	175
2	175	175	175	175	150	150	175	175
3	175	175	175	175	175	175	150	150
4	225	225	225	225	225	225	175	175
5	225	225	250	250	275	275	225	225
6	225	225	275	275	275	300	275	275
7	200	225	275	275	250	275	275	275
8	200	200	275	275	225	225	275	275
9	175	200	225	225	200	225	225	225
10	200	200	225	200	175	225	175	200
11	200	225	250	200	200	225	175	200
12	175	225	225	225	200	275	175	250
13	175	200	225	200	200	250	175	225
14	175	225	250	200	175	225	175	250
15	175	200	225	225	175	225	225	250
16	175	225	250	250	200	200	275	275
17	200	225	250	275	250	250	300	300
18	225	250	250	250	275	275	250	275
29	250	275	250	250	250	250	250	250
20	200	250	250	250	250	250	200	200
21	200	200	250	250	250	250	225	225
22	200	200	275	275	200	200	200	200
23	200	200	275	275	225	225	200	200

Table 7-12: Change from Current Regulation Requirements (MWs)

Hour Beginning	April - May 2024 3,500 MW Wind 3,000 MW Solar	June - August 2024 3,500 MW Wind 3,000 MW Solar	September - October 2024 3,500 MW Wind 3,000 MW Solar	November - March 2024 3,500 MW Wind 3,000 MW Solar
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	25	0
7	25	0	25	0
8	0	0	0	0
9	25	0	25	0
10	0	-25	50	25
11	25	-50	25	25
12	50	0	75	75
13	25	-25	50	50
14	50	-50	50	75
15	25	0	50	25
16	50	0	0	0
17	25	25	0	0
18	25	0	0	25
29	25	0	0	0
20	50	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0

7.4. Analysis of Scenarios 1 and 2

The current regulation study examined the joint impact of wind and solar on net-load variability. These results were compared to the results of the 2010 Wind Study and the current level of regulation requirements. The following observations can be made with respect to Scenarios 1 and 2.

- Regulation requirements for Scenario 1 are consistent with current requirements and less than those for Scenario 2. This result is expected since Scenario 1 has lower levels of load, wind, and solar resources than Scenario 2.
- Requirements for Scenario 2 compared to current production levels are mixed (Figure 7-5). For most hours, regulation requirements, if adopted, would be only be slightly higher in the spring, fall, and winter periods. During summer, the projected requirements are generally consistent with current requirements for most hours but less than current levels in the mid-day hours.

Regulation requirements are generally lower in the summer months because load and solar PV tend to move together during the cooling season and are much more closely correlated than during other seasons. During the mornings, both load and solar PV are increasing rapidly. During mid-day, they increase more slowly then begin a gradual decline later in the afternoon. Then, in the early evening hours, load and solar PV both decline rapidly. Since the solar PV MW reduces load, it also reduces the variability of load when solar PV and load increase or decrease, in synch. In contrast to the cooling season, during the winter heating season solar PV MW is decreasing over the course of the afternoon, while net load tends to build (before decreasing again after 7 pm), which increases the regulation requirements.

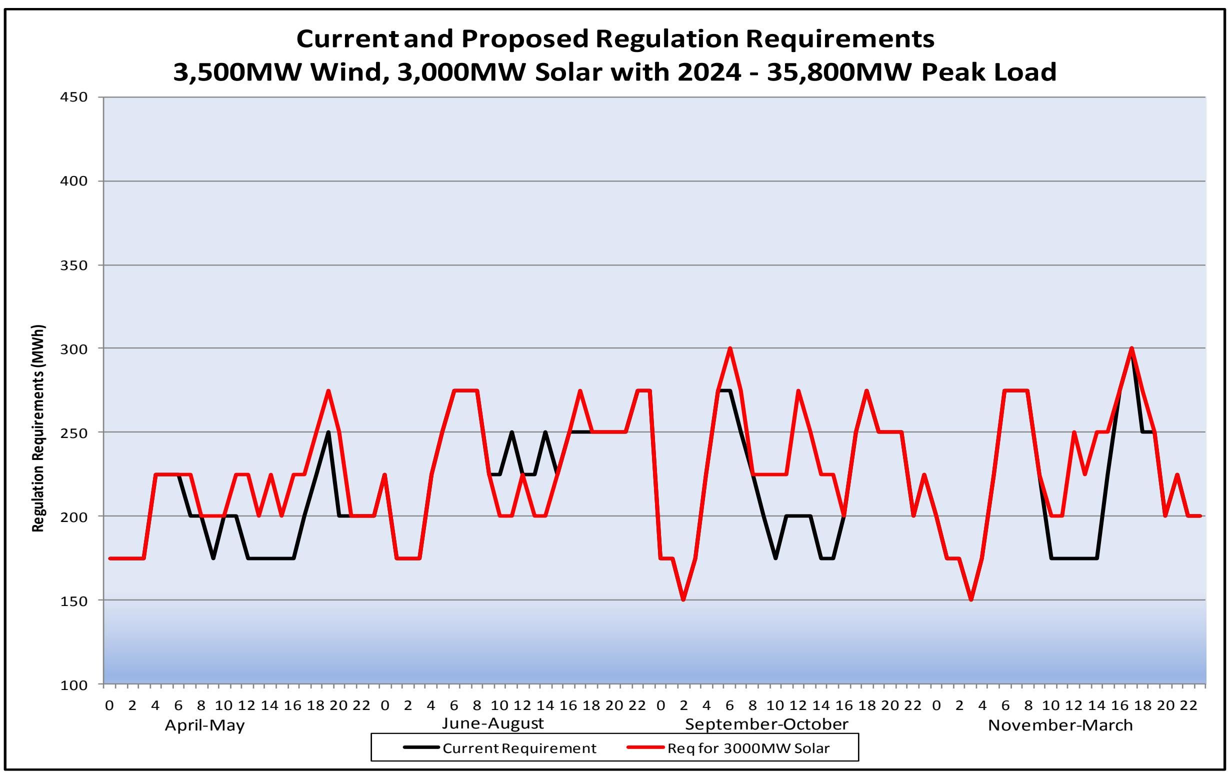

Figure 7-10: Comparison of Scenario 2 to Current Requirements

7.5. Scenario 3a-3d

The following tables and figures summarize the raw results for the four most aggressive scenarios - Scenarios 3a, 3b, 3c, and 3d - which studied the variability of system net load with wind penetration at 4,500 MW and solar PV penetration ranging from 4,500 MW to 9,000 MW. NYISO Operations performed an abbreviated analysis of these scenarios and determined that an increase of 1,500 MW in solar PV penetration from 2019 to 2030 increased the average regulation requirement from 226 MW to 278 MW (or 52 MW). Increasing the 2030 solar MW from 4,500 MW to 9,000 MW resulted in an increase in the average regulation requirement to 347 MW (or 69 MW) from the 4,500 MW level. This average increase of 69 MW consisted of hourly increases of 62 MW in April–May; 30 MW in June–August; 81 MW in September–October; and 107 MW in November–March. All hours are in Eastern Standard time.

Table 7-13: Scenario 3a Winter Regulation Results (MWs)

Winter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	182	131	105	99	110	201	274	220	164	142	131	120	141	126	112	122	259	268	246	128	143	167	171	179
3σ Load - Wind Only	268	284	231	219	215	254	321	271	226	213	195	199	265	240	251	230	309	302	296	232	208	236	248	247
3σ Load - Solar Only	182	131	105	99	110	201	275	284	334	215	176	183	187	188	168	219	222	270	245	128	143	167	171	179
3σ Load - (Wind & Solar)	268	284	231	219	215	254	321	328	357	268	230	230	299	278	283	295	287	302	296	232	208	236	248	247
2010: 2006 Results	189	143	160	142	135	201	287	256	211	180	161	153	143	152	166	156	234	294	254	183	198	197	186	188
Current Prod. Values	200	175	175	150	175	225	275	275	275	225	175	175	175	175	175	225	275	300	250	250	200	225	200	200

Table 7-14: Scenario 3a Summer Regulation Results (MWs)

Summer	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	134	108	103	107	176	237	188	142	146	136	127	134	118	111	113	113	131	165	205	186	180	173	167	161
3σ Load - Wind Only	271	270	276	272	305	316	263	245	243	223	208	213	256	202	186	225	236	326	315	318	282	367	302	262
3σ Load - Solar Only	134	108	103	107	172	234	240	164	167	150	144	169	163	172	171	152	162	162	164	185	180	173	167	161
3σ Load - (Wind & Solar)	271	270	276	272	305	315	270	251	259	220	212	235	270	228	227	261	256	333	309	312	282	367	302	262
2010: 2006 Results	173	152	164	167	193	208	187	198	168	157	178	181	215	221	202	181	259	231	217	258	216	226	233	216
Current Prod. Values	225	175	175	175	225	250	275	275	275	225	225	250	225	225	250	225	250	250	250	250	250	250	275	275

Table 7-15: Scenario 3a Spring Regulation Results (MWs)

Spring	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	124	101	98	127	183	246	192	163	141	126	121	113	120	116	108	110	123	154	218	236	171	169	149	150
3σ Load - Wind Only	271	263	215	231	252	311	256	238	195	207	197	219	238	201	229	210	233	263	279	276	270	255	271	240
3σ Load - Solar Only	124	101	98	127	183	248	262	199	186	186	158	165	172	162	178	162	158	180	190	236	171	169	149	150
3σ Load - (Wind & Solar)	271	263	215	231	252	319	318	249	219	251	221	269	278	242	278	228	250	263	261	276	270	255	271	240
2010: 2006 Results	161	144	131	129	204	249	183	208	160	181	158	174	186	199	181	195	191	203	235	246	211	203	175	175
Current Prod. Values	175	175	175	175	225	225	225	200	200	175	200	200	175	175	175	175	175	200	225	250	200	200	200	200

Table 7-16: Scenario 3a Fall Regulation Results (MWs)

Fall	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	112	100	88	108	192	286	202	134	134	141	112	102	91	93	89	100	134	225	194	144	143	141	145	134
3σ Load - Wind Only	276	279	233	202	257	347	272	226	204	219	185	187	268	255	212	204	221	316	308	250	233	265	242	230
3σ Load - Solar Only	112	100	88	108	192	289	271	296	185	184	146	149	165	157	168	149	182	206	190	144	143	141	145	134
3σ Load - (Wind & Solar)	276	279	233	202	257	350	324	334	239	256	205	210	331	310	273	222	252	283	303	250	233	265	242	230
2010: 2006 Results	149	151	133	145	206	271	203	200	178	159	154	156	179	177	164	162	172	251	214	196	199	193	164	172
Current Prod. Values	175	175	150	175	225	275	275	250	225	200	175	200	200	200	175	175	200	250	275	250	250	250	200	225

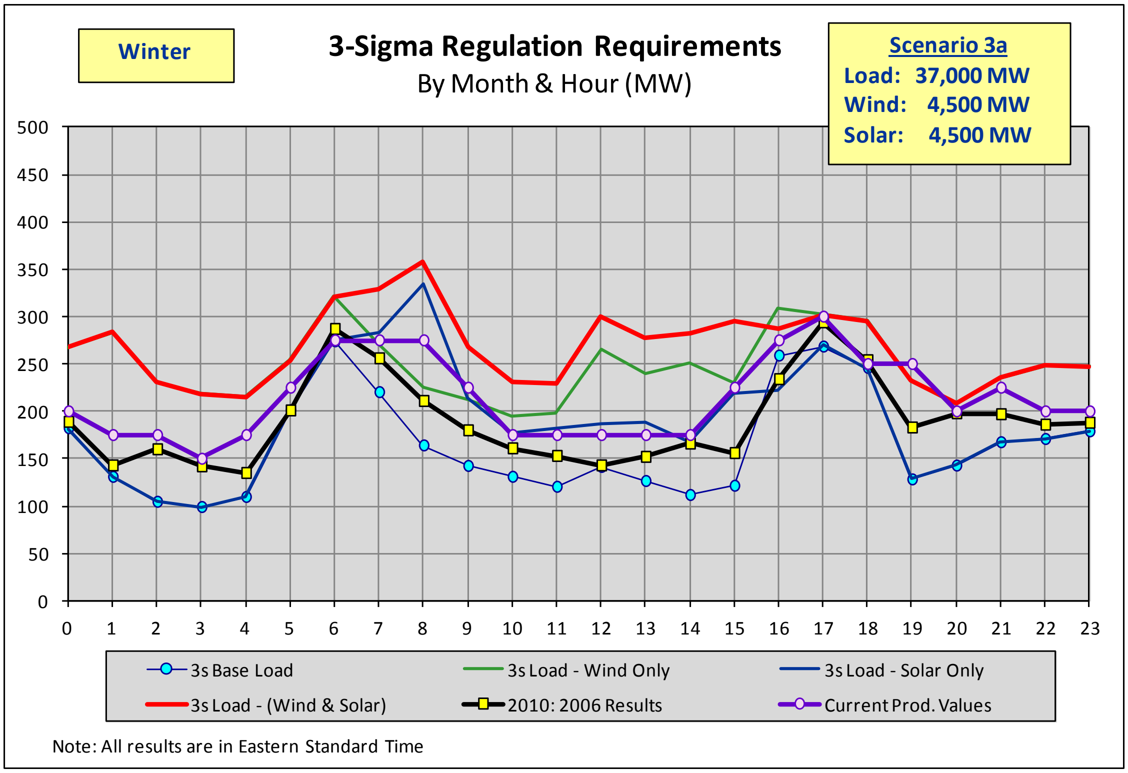

Figure 7-11: Scenario 3a Winter Regulation Results

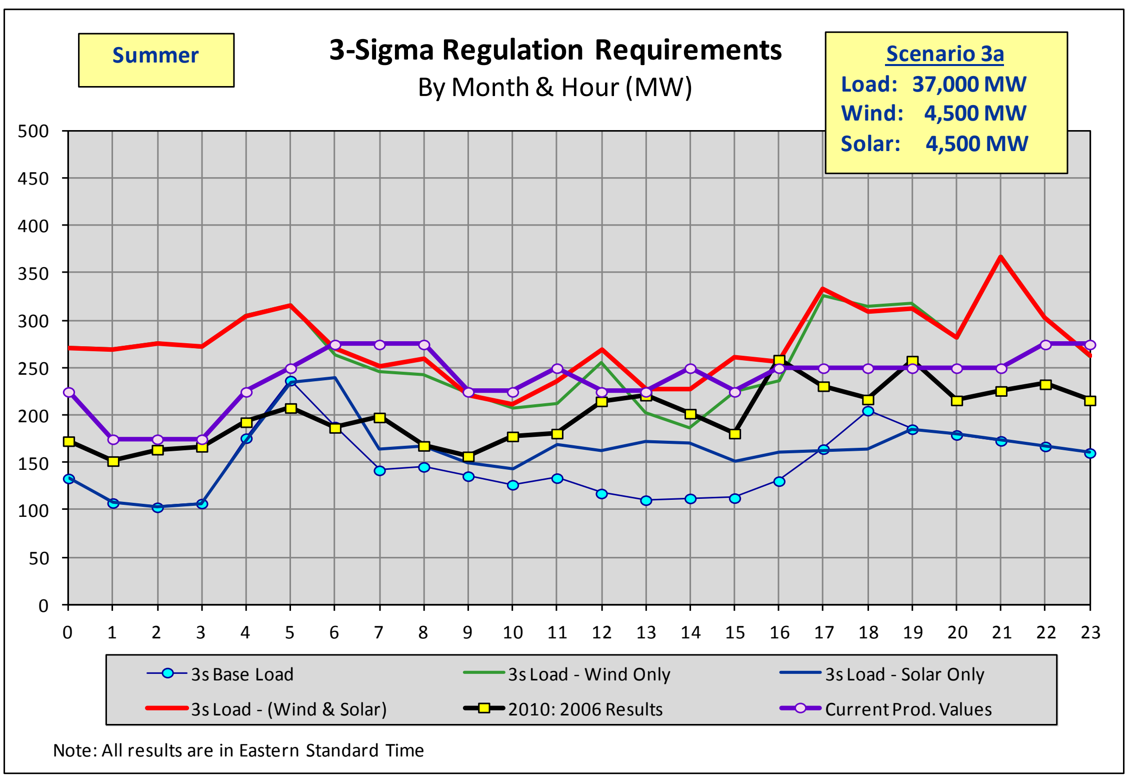

Figure 7-12: Scenario 3a Summer Regulation Results

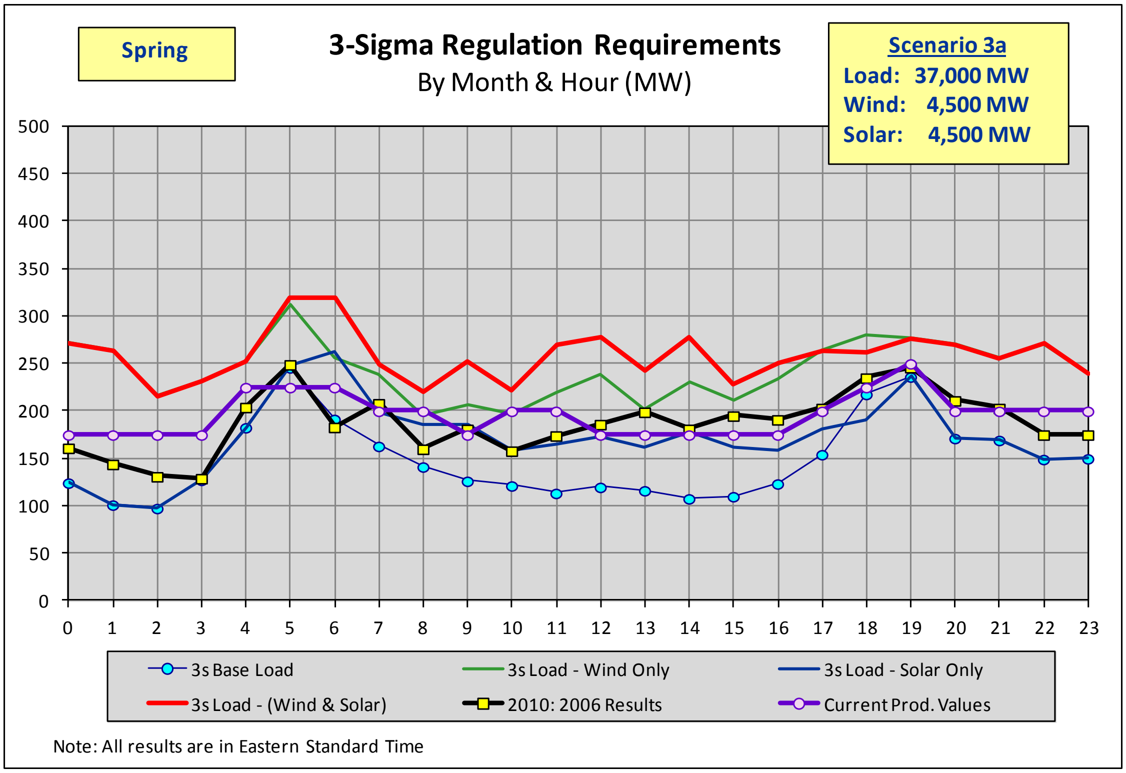

Figure 7-13: Scenario 3a Spring Regulation Results

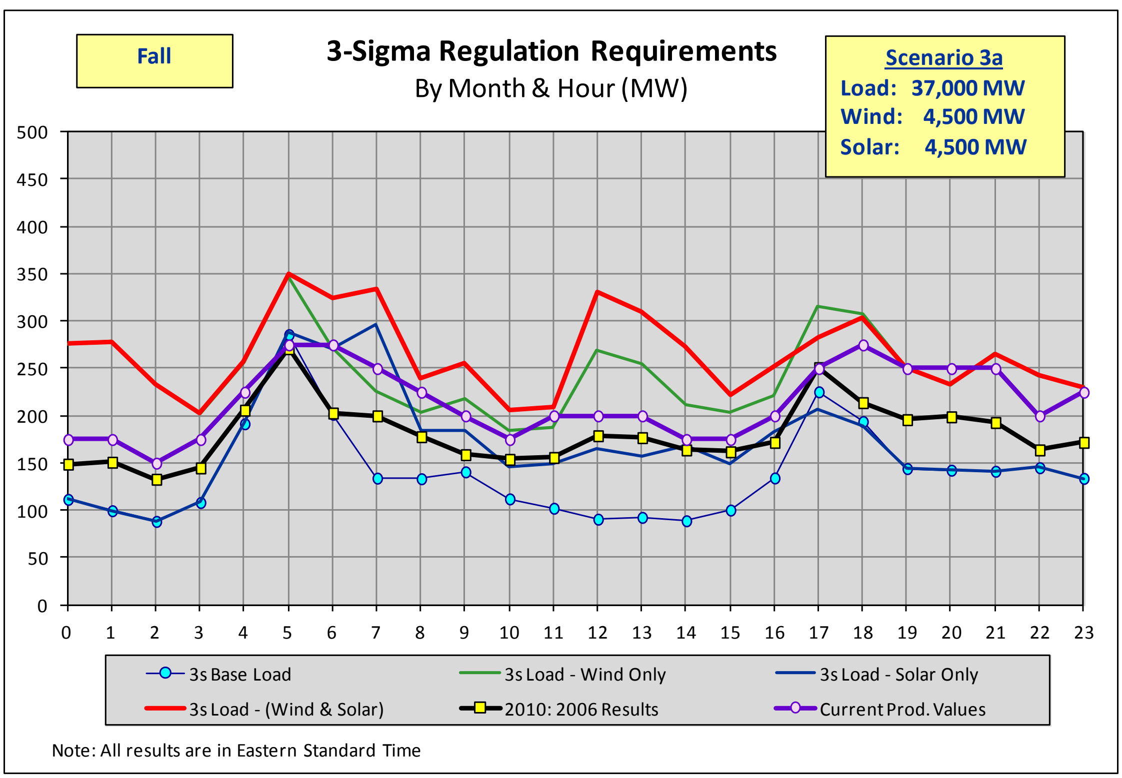

Figure 7-14: Scenario 3a Fall Regulation Results

Table 7-17: Scenario 3b Winter Regulation Results (MWs)

Winter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	153	120	96	87	103	190	263	182	147	127	117	108	114	106	102	112	187	220	176	117	123	150	156	154
3σ Load - Wind Only	233	217	190	182	174	227	291	235	210	179	174	176	206	195	192	195	244	268	231	192	182	214	210	216
3σ Load - Solar Only	153	120	95.6	87.4	103	190	269	249	269	185	168	152	166	155	157	185	187	224	176	117	123	150	156	154
3σ Load - (Wind & Solar)	233	217	190	182	174	227	297	291	306	219	211	199	237	221	235	252	248	274	231	192	182	214	210	216
2010: 2006 Results	164	136	133	129	125	183	263	216	190	158	148	139	130	137	136	129	182	220	186	163	168	183	178	163
Current Prod. Values	200	175	175	150	175	225	275	275	275	225	175	175	175	175	175	225	275	300	250	250	200	225	200	200

Table 7-18: Scenario 3b Summer Regulation Results (MWs)

Summer	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	128	105	100	106	169	222	184	140	136	132	122	116	111	106	109	109	127	161	156	180	168	160	165	153
3σ Load - Wind Only	225	229	240	207	240	272	238	214	202	208	188	195	188	190	187	206	242	271	267	265	261	271	245	230
3σ Load - Solar Only	128	105	100	106	167	217	209	157	152	144	141	153	157	159	160	146	152	159	140	174	168	160	165	153
3σ Load - (Wind & Solar)	225	229	240	207	239	269	258	220	209	212	194	218	223	221	214	221	256	260	256	261	261	271	245	230
2010: 2006 Results	155	138	143	150	179	200	186	179	160	147	162	171	178	186	184	175	199	208	193	210	203	214	202	184
Current Prod. Values	225	175	175	175	225	250	275	275	275	225	225	250	225	225	250	225	250	250	250	250	250	250	275	275

Table 7-19: Scenario 3b Spring Regulation Results (MWs)

Spring	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	120	98	93	119	180	243	182	147	134	117	114	110	109	105	102	105	115	149	186	206	159	156	139	142
3σ Load - Wind Only	221	215	193	209	231	267	233	210	178	205	194	190	226	204	199	193	211	230	260	258	248	224	220	228
3σ Load - Solar Only	120	98	93	119	179	247	250	191	177	169	152	153	154	157	172	162	154	173	165	206	159	156	139	142
3σ Load - (Wind & Solar)	221	215	193	209	230	272	281	235	199	229	220	228	255	236	245	211	223	242	252	258	248	224	220	228
2010: 2006 Results	161	142	128	124	196	245	182	183	159	159	152	163	162	165	156	162	169	185	210	237	200	195	167	167
Current Prod. Values	175	175	175	175	225	225	225	200	200	175	200	200	175	175	175	175	175	200	225	250	200	200	200	200

Table 7-20: Scenario 3b Fall Regulation Results (MWs)

Fall	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	108	88	78	98	185	276	184	132	123	131	102	93	89	89	86	95	124	205	173	124	136	132	137	133
3σ Load - Wind Only	231	211	194	173	231	317	233	204	187	202	166	181	222	207	190	182	202	281	250	214	206	237	228	206
3σ Load - Solar Only	108	88.3	78.4	97.9	185	277	261	280	179	176	141	147	162	152	164	142	160	185	171	124	136	132	137	133
3σ Load - (Wind & Solar)	231	211	194	173	231	318	301	307	218	234	182	196	275	259	242	211	220	252	248	214	206	237	228	206
2010: 2006 Results	144	137	132	143	197	268	189	193	169	155	151	151	159	157	159	155	168	240	185	196	181	181	155	164
Current Prod. Values	175	175	150	175	225	275	275	250	225	200	175	200	200	200	175	175	200	250	275	250	250	250	200	225

All hours are in Eastern Standard Time

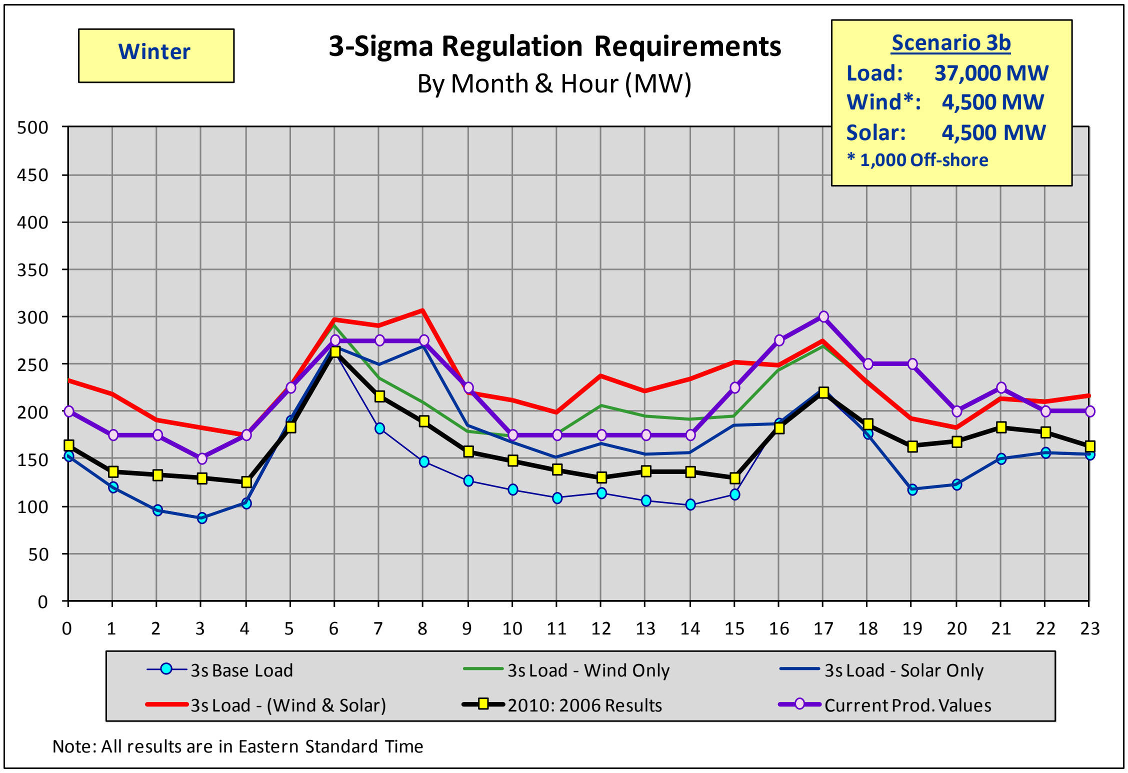

Figure 7-15: Scenario 3b Winter Regulation Results

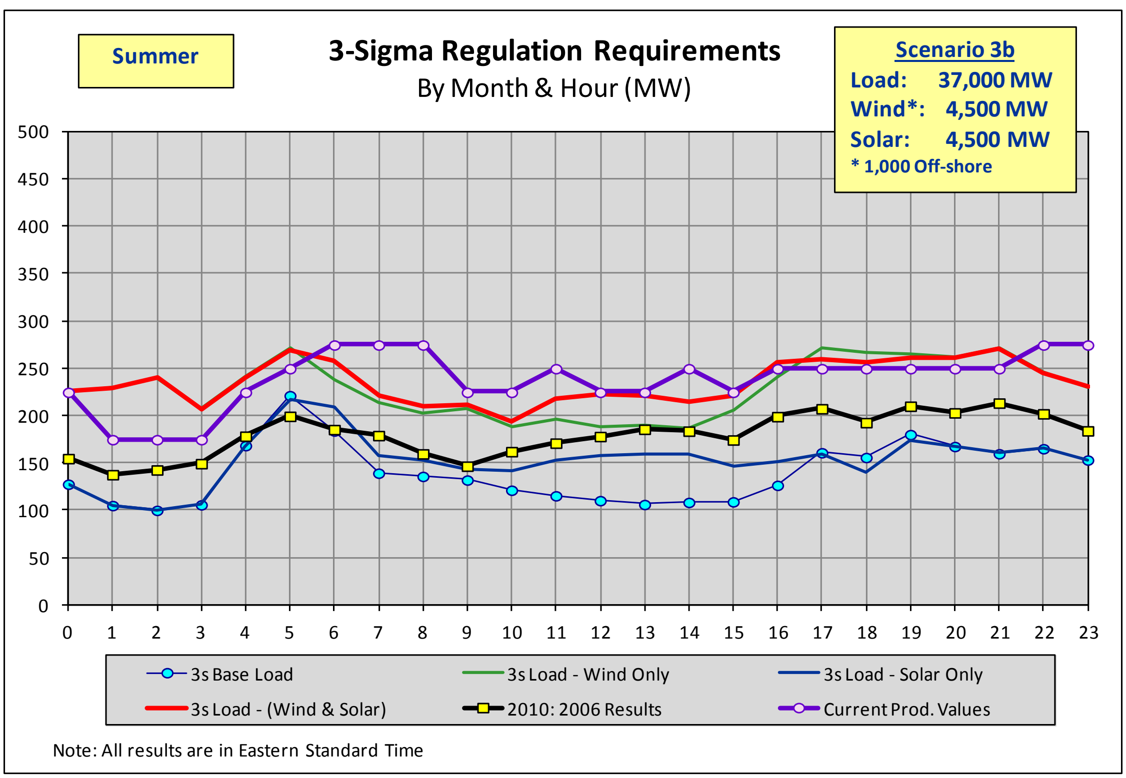

Figure 7-16: Scenario 3b Summer Regulation Results

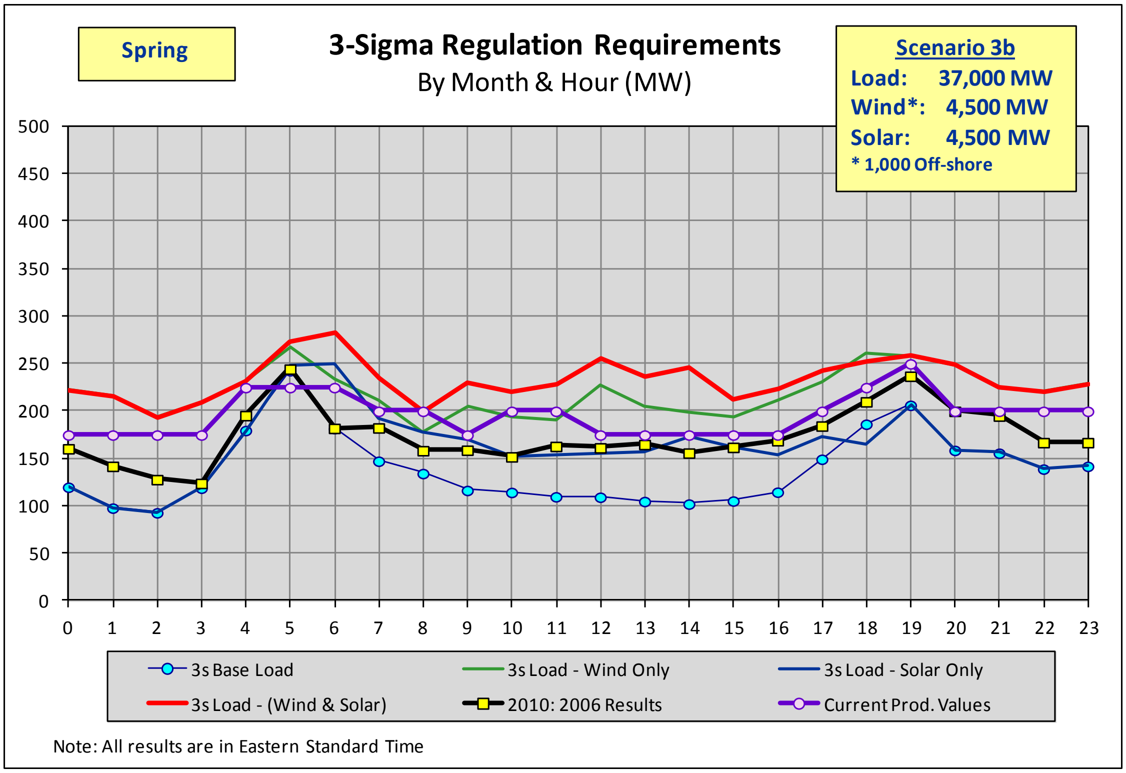

Figure 7-17: Scenario 3b Spring Regulation Results

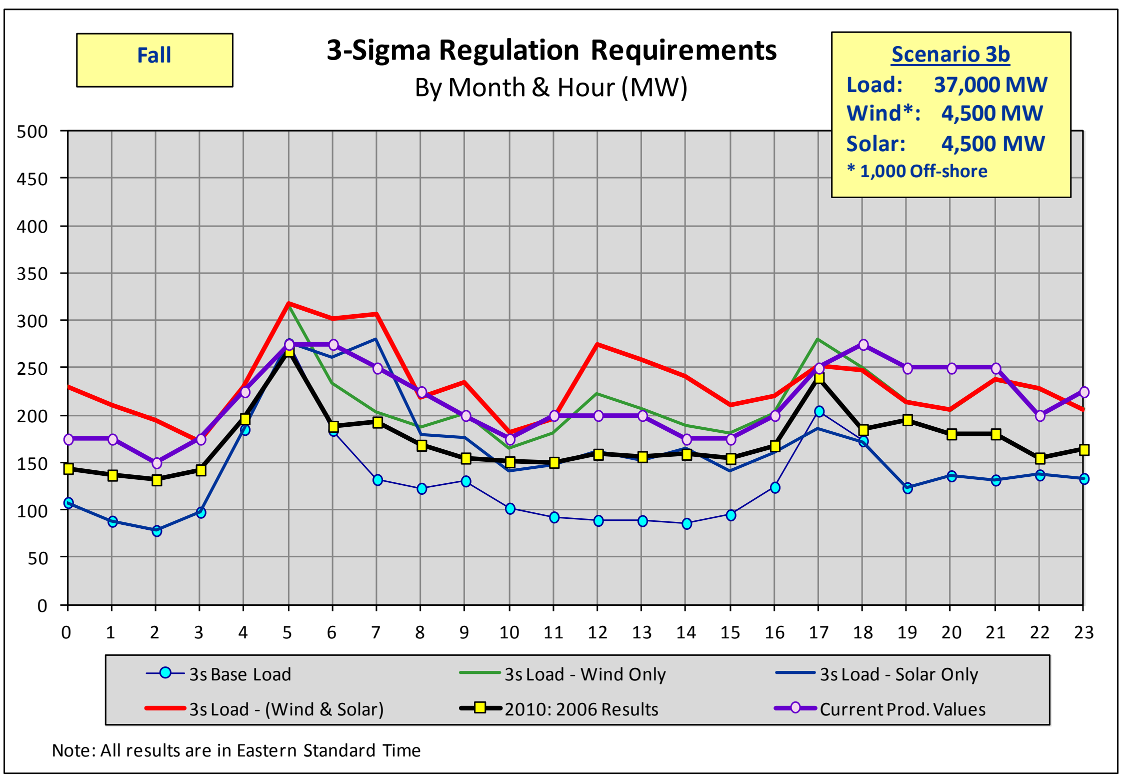

Figure 7-18: Scenario 3b Fall Regulation Results

Table 7-21: Scenario 3c Winter Regulation Results (MWs)

Winter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	182	131	105	99	110	201	274	220	164	142	131	120	141	126	112	122	259	268	246	128	143	167	171	179
3σ Load - Wind Only	268	284	231	219	215	254	321	271	226	213	195	199	265	240	251	230	309	302	296	232	208	236	248	247
3σ Load - Solar Only	182	131	105	99	110	201	337	439	631	329	273	304	297	301	295	405	346	329	247	128	143	167	171	179
3σ Load - (Wind & Solar)	268	284	231	219	215	254	385	451	640	368	313	325	378	365	347	454	401	378	296	232	208	236	248	247
2010: 2006 Results	189	143	160	142	135	201	287	256	211	180	161	153	143	152	166	156	234	294	254	183	198	197	186	188
Current Prod. Values	200	175	175	150	175	225	275	275	275	225	175	175	175	175	175	225	275	300	250	250	200	225	200	200

Table 7-22: Scenario 3c Summer Regulation Results (MWs)

Summer	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	134	108	103	107	176	237	188	142	146	136	127	134	118	111	113	113	131	165	205	186	180	173	167	161
3σ Load - Wind Only	271	270	276	272	305	316	263	245	243	223	208	213	256	202	186	225	236	326	315	318	282	367	302	262
3σ Load - Solar Only	134	108	103	107	172	252	377	241	235	221	235	260	262	282	277	242	232	217	194	184	180	173	167	161
3σ Load - (Wind & Solar)	271	270	276	272	306	330	388	286	306	269	268	298	315	294	306	333	305	359	337	306	282	367	302	262
2010: 2006 Results	173	152	164	167	193	208	187	198	168	157	178	181	215	221	202	181	259	231	217	258	216	226	233	216
Current Prod. Values	225	175	175	175	225	250	275	275	275	225	225	250	225	225	250	225	250	250	250	250	250	250	275	275

Table 7-23: Scenario 3c Spring Regulation Results (MWs)

Spring	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	124	101	98	127	183	246	192	163	141	126	121	113	120	116	108	110	123	154	218	236	171	169	149	150
3σ Load - Wind Only	271	263	215	231	252	311	256	238	195	207	197	219	238	201	229	210	233	263	279	276	270	255	271	240
3σ Load - Solar Only	124	101	98	127	183	277	414	314	291	324	251	255	269	256	291	276	274	296	212	237	171	169	149	150
3σ Load - (Wind & Solar)	271	263	215	231	252	342	451	341	291	362	297	347	354	321	367	301	294	316	294	276	270	255	271	240
2010: 2006 Results	161	144	131	129	204	249	183	208	160	181	158	174	186	199	181	195	191	203	235	246	211	203	175	175
Current Prod. Values	175	175	175	175	225	225	225	200	200	175	200	200	175	175	175	175	175	200	225	250	200	200	200	200

Table 7-24: Scenario 3c Fall Regulation Results (MWs)

Fall	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	112	100	88	108	192	286	202	134	134	141	112	102	91	93	89	100	134	225	194	144	143	141	145	134
3σ Load - Wind Only	276	279	233	202	257	347	272	226	204	219	185	187	268	255	212	204	221	316	308	250	233	265	242	230
3σ Load - Solar Only	112	100	88	108	192	292	427	548	311	279	227	257	288	262	293	268	341	262	188	144	143	141	145	134
3σ Load - (Wind & Solar)	276	279	233	202	257	353	468	546	338	339	268	280	429	395	376	312	382	330	301	250	233	265	242	230
2010: 2006 Results	149	151	133	145	206	271	203	200	178	159	154	156	179	177	164	162	172	251	214	196	199	193	164	172
Current Prod. Values	175	175	150	175	225	275	275	250	225	200	175	200	200	200	175	175	200	250	275	250	250	250	200	225

All hours are in Eastern Standard Time.

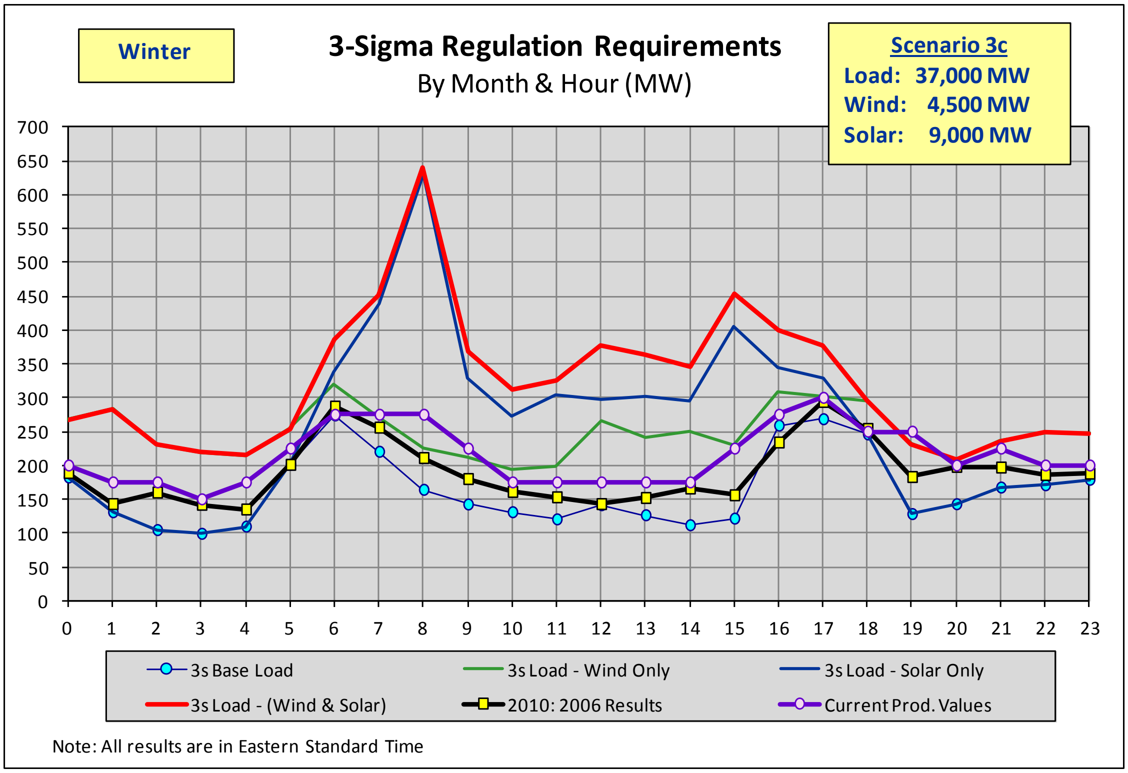

Figure 7-19: Scenario 3c Winter Regulation Results

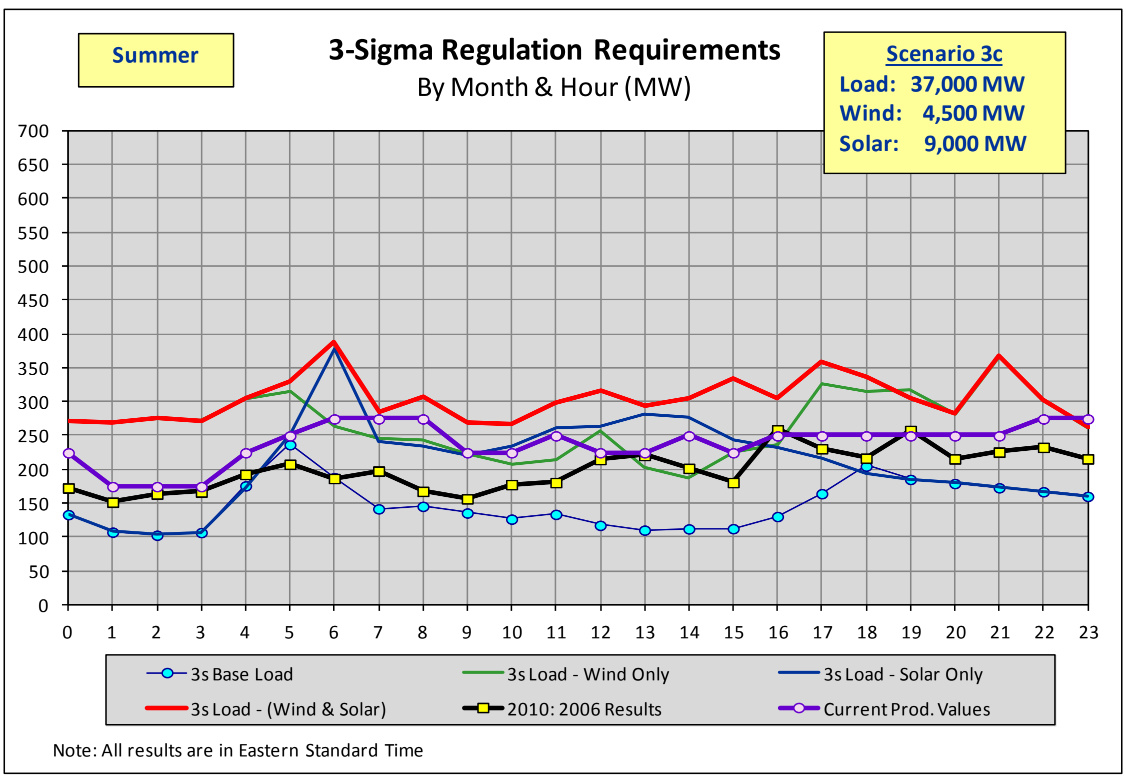

Figure 7-20: Scenario 3c Summer Regulation Results

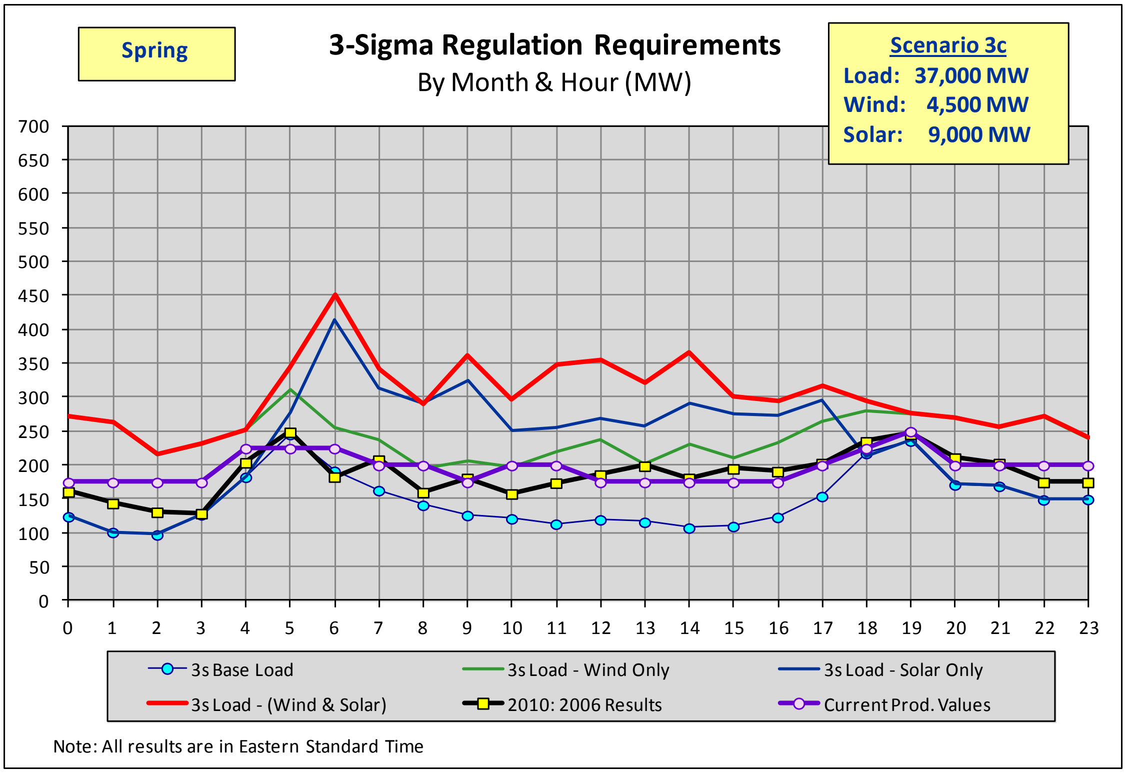

Figure 7-21: Scenario 3c Spring Regulation Results

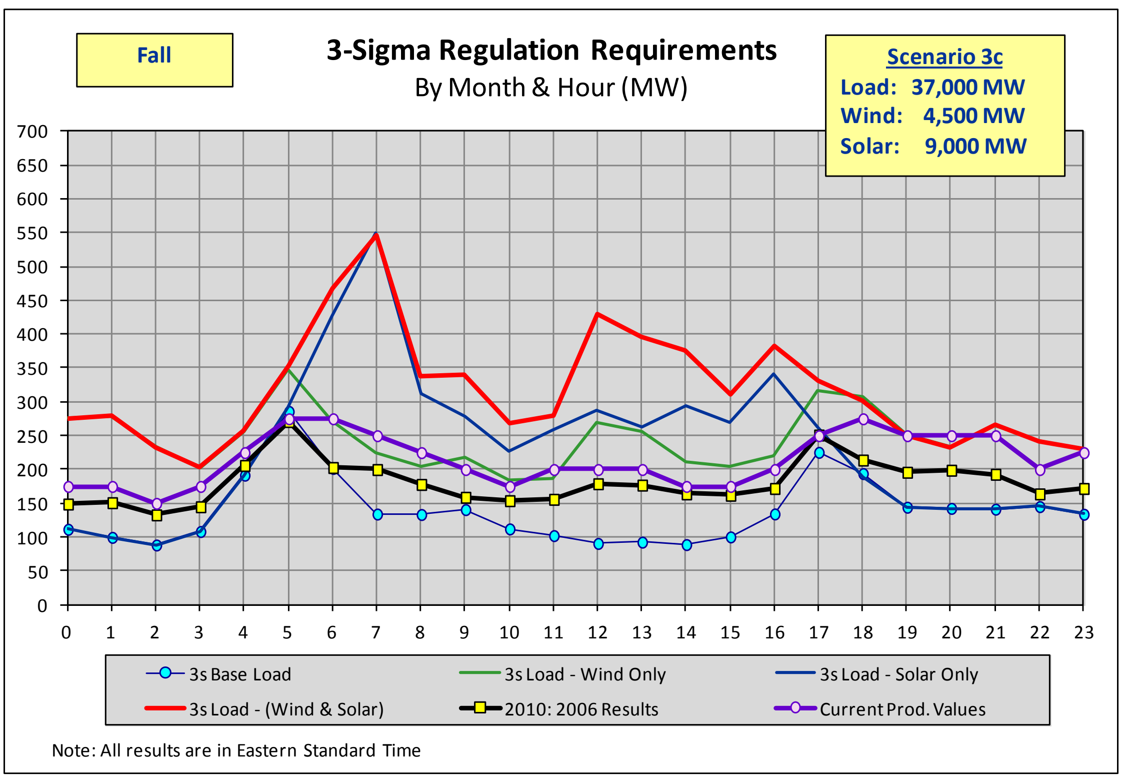

Figure 7-22: Scenario 3c Fall Regulation Results

Table 7-25: Scenario 3d Winter Regulation Results (MWs)

Winter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	182	131	105	99	110	201	274	220	164	142	131	120	141	126	112	122	259	268	246	128	143	167	171	179
3σ Load - Wind Only	253	255	197	196	186	238	305	265	243	198	183	216	232	224	231	201	300	295	287	215	197	238	229	235
3σ Load - Solar Only	182	131	105	99	110	201	337	439	631	329	273	304	297	301	295	405	346	329	247	128	143	167	171	179
3σ Load - (Wind & Solar)	253	255	197	196	186	238	381	453	643	351	304	335	351	358	353	441	416	362	287	215	197	238	229	235
2010: 2006 Results	189	143	160	142	135	201	287	256	211	180	161	153	143	152	166	156	234	294	254	183	198	197	186	188
Current Prod. Values	200	175	175	150	175	225	275	275	275	225	175	175	175	175	175	225	275	300	250	250	200	225	200	200

Table 7-26: Scenario 3d Summer Regulation Results (MWs)

Summer	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	134	108	103	107	176	237	188	142	146	136	127	134	118	111	113	113	131	165	205	186	180	173	167	161
3σ Load - Wind Only	238	237	247	228	265	293	250	231	218	234	192	211	195	197	203	214	263	283	285	290	288	335	261	246
3σ Load - Solar Only	134	108	103	107	172	252	377	241	235	221	235	260	262	282	277	242	232	217	194	184	180	173	167	161
3σ Load - (Wind & Solar)	238	237	247	228	266	308	387	272	276	286	258	291	321	302	309	312	328	316	330	279	288	335	261	246
2010: 2006 Results	173	152	164	167	193	208	187	198	168	157	178	181	215	221	202	181	259	231	217	258	216	226	233	216
Current Prod. Values	225	175	175	175	225	250	275	275	275	225	225	250	225	225	250	225	250	250	250	250	250	250	275	275

Table 7-27: Scenario 3d Spring Regulation Results (MWs)

Spring	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	124	101	98	127	183	246	192	163	141	126	121	113	120	116	108	110	123	154	218	236	171	169	149	150
3σ Load - Wind Only	233	229	194	214	236	284	236	227	184	206	204	202	253	215	224	206	223	255	264	271	264	240	256	239
3σ Load - Solar Only	124	101	98	127	183	277	414	314	291	324	251	255	269	256	291	276	274	296	212	237	171	169	149	150
3σ Load - (Wind & Solar)	233	229	194	214	236	320	435	318	280	343	304	328	363	323	366	296	295	323	295	271	264	240	256	239
2010: 2006 Results	161	144	131	129	204	249	183	208	160	181	158	174	186	199	181	195	191	203	235	246	211	203	175	175
Current Prod. Values	175	175	175	175	225	225	225	200	200	175	200	200	175	175	175	175	175	200	225	250	200	200	200	200

Table 7-28: Scenario 3d Fall Regulation Results (MWs)

Fall	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3σ Base Load	112	100	88	108	192	286	202	134	134	141	112	102	91	93	89	100	134	225	194	144	143	141	145	134
3σ Load - Wind Only	237	234	198	186	240	329	252	210	191	205	174	189	227	231	216	187	207	294	267	226	214	243	237	210
3σ Load - Solar Only	112	100	88	108	192	292	427	548	311	279	227	257	288	262	293	268	341	262	188	144	143	141	145	134
3σ Load - (Wind & Solar)	237	234	198	186	240	334	456	532	339	332	258	269	392	371	374	312	373	304	258	226	214	243	237	210
2010: 2006 Results	149	151	133	145	206	271	203	200	178	159	154	156	179	177	164	162	172	251	214	196	199	193	164	172
Current Prod. Values	175	175	150	175	225	275	275	250	225	200	175	200	200	200	175	175	200	250	275	250	250	250	200	225

All hours are in Eastern Standard Time

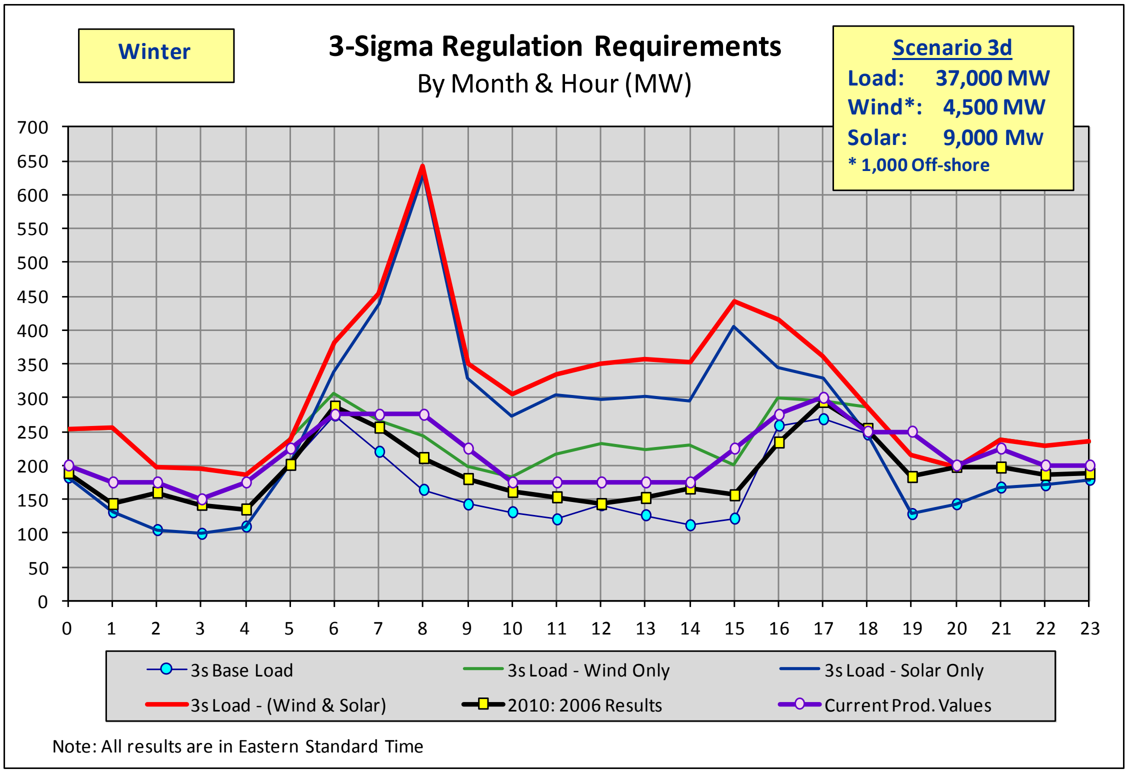

Figure 7-23: Scenario 3d Winter Regulation Results

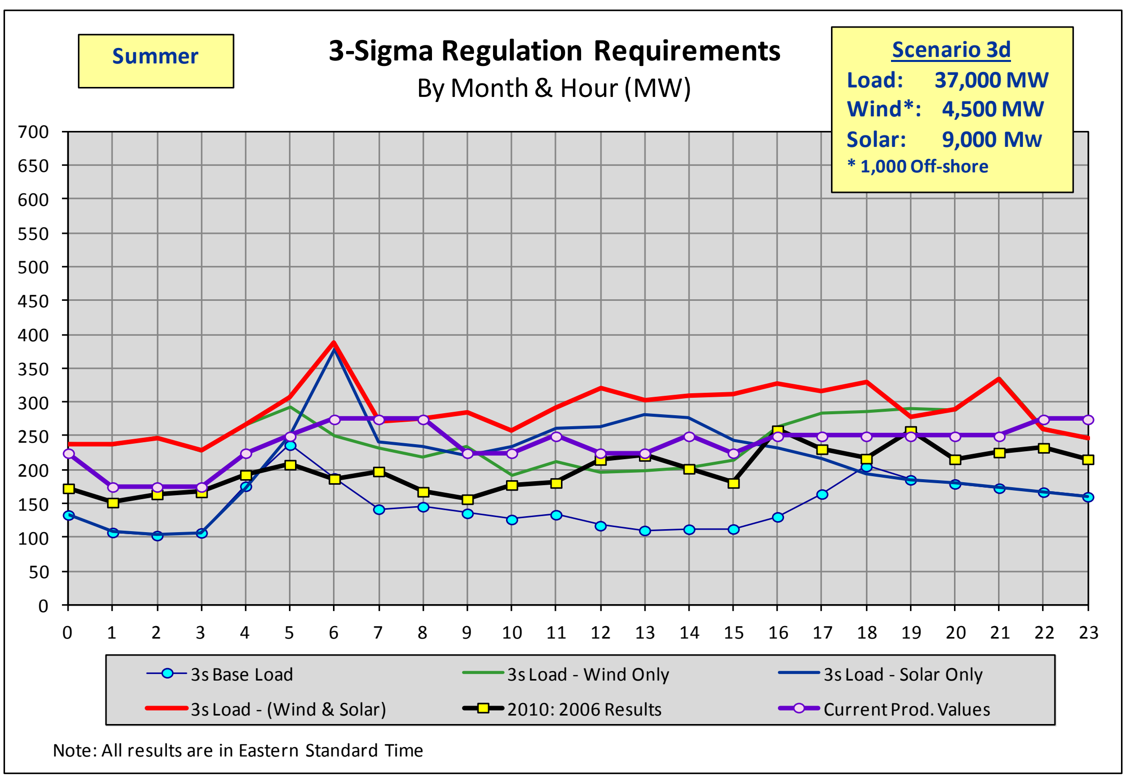

Figure 7-24: Scenario 3d Summer Regulation Results

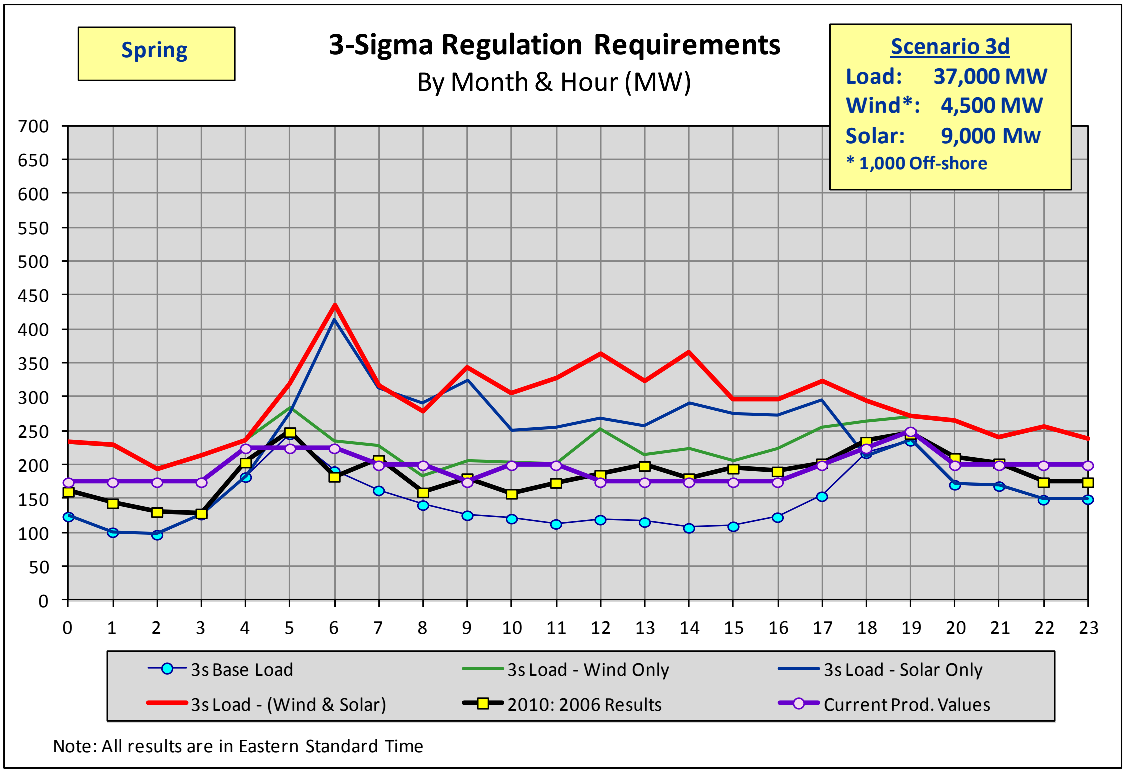

Figure 7-25: Scenario 3d Spring Regulation Results

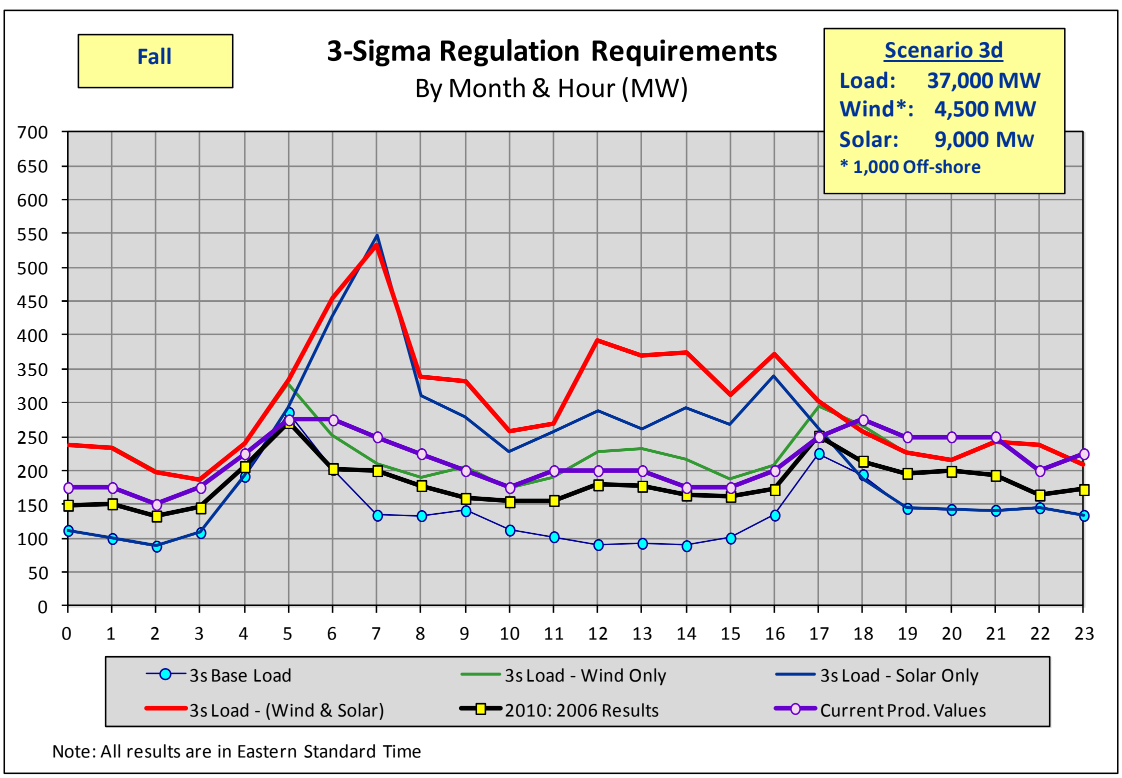

Figure 7-26: Scenario 3d Fall Regulation Results

7.6. System Regulation Requirement Findings and Recommendations

The NYISO's specific findings associated with system regulation requirements are summarized below:

- Because of their variable nature and limited ability to dispatch, the addition of solar PV and wind resources on a large-scale basis will result in a system that is more variable than a system without these intermittent resources. This is observed in higher 3-sigma values as the MW of solar PV and wind resources are increased above 1,500 MW in Scenarios 2 and Scenario 3.

- Study results indicate that minor upward revisions in the regulation requirements may be required as the penetration levels of solar PV exceed 1,500 MW or of wind exceed 2,500 MW. There is also upward pressure on regulation requirements as the penetration levels increase to 9,000 MW of solar PV and to 4,500 MW of wind,[11] but the projected increases are not material and can readily be accommodated within the current market rules and system operations. Nevertheless, it is recommended that the NYISO continue to track solar PV and wind penetration levels to assess and periodically make minor adjustments, as appropriate, to the current minimum regulation requirements for the bulk power system to accommodate the higher average levels of regulation needed and increased seasonal variability in the regulation requirements introduced by solar PV resources. As penetration levels increase, it is recommended that the NYISO periodically assess the potential of storage technologies within the state to mitigate against the potential of higher levels of regulation.

[11] The highest penetration values studied (*i.e.*, 9,000 MW of solar PV and 4,500 MW of wind) are not intended to reflect a ceiling for the integration of intermittent resources but are a reasonable projection of the maximum achievable in the next 5 to 10 years. Similarly, in its 2010 Wind Study the NYISO studied the impact on regulation requirements of up to 8,000 MW of wind which was considered to be the maximum achievable wind penetration within the time-frame studied.

8. Results for Task 4b- Frequency and Voltage Ride Through

8.1. Overview

The addition of large amounts of solar PV power may cause frequency and voltage reliability issues that the NYISO will need to address. The New York Bulk Power System (BPS) is designed and operated in a manner to avoid cascading outages of generation and transmission elements. Generation is expected to stay online during system disturbances. The intention is to avoid adding additional stress to the BPS when it may be already heavily stressed due to a disturbance. Early wind power projects did not have the inherent capability to remain on-line during close-in faults. This situation was resolved by FERC with the addition of Low Voltage Ride Through (VLRT) requirements for wind power projects in FERC's *pro forma* tariffs.

There are no high/low voltage or frequency ride-through requirements for solar PV power at present in New York. FERC has not imposed ride-through requirements on solar projects under their jurisdiction (*i.e.*, interconnected via ISO/RTO procedures). Small projects (non-FERC jurisdictional, interconnected via local Transmission Owners—"TOs") commonly are connected to distribution systems and fall under the scope of IEEE Standard 1547/1547a and Underwriters Laboratories 1741 (collectively, hereinafter "Standards"). These Standards presently have no requirement for a generator to stay online during disturbances. In fact, they require generation to drop off-line if voltages or frequencies go outside certain limits. Further, they allow generators to drop off-line for any level of disturbance. Fortunately, these Standards are in the revision process and are expected to provide requirements for ride through sometime in the future.

Voltage disturbances are commonly caused by short circuits. High voltage system short circuits cause voltage dips, and clearing these faults can cause both voltage depressions and swells. Such voltage deviations could result in loss of nearby solar PV installations. This additional loss of output would constitute a second, simultaneous contingency—an event for which the system is neither designed nor studied. Tripping of significant solar PV during a critical contingency could produce more significant consequences than would be the case for the critical contingency without solar PV installations.

Frequency disturbances are commonly caused by sudden generation or load trips. Frequency changes are generally not localized but are experienced by the entire interconnected system. The potential exists for a large portion of the NYISO solar PV to be lost during a significant frequency drop. This would cause the frequency drop to be deeper and its recovery to be longer.

There are several other issues that may be caused by the addition of large amounts of solar PV within New York, including voltage fluctuations, power quality, and islanding. However, these issues affect primarily the local distribution networks and are not a significant cause of concern to the NYISO's operation of the BPS. Accordingly, these issues are not addressed in this report. The local TOs should consider addressing these issues within their own interconnection procedures.

8.2. Inverter Technologies

Several inverter manufacturers offer products with advanced features. These products are often referred to as 'smart inverters,' and are capable of providing ride through, voltage regulation, and advanced anti-islanding detection, as well as other power quality features. These features are either becoming required or are already required in several localities, especially those with high solar PV penetration, such as Germany and Hawaii. They have become mandatory in California through the enactment of Rule 21. However, inverters in the U.S. are generally certified to the current version of UL 1741, which prohibits implementing ride-through features. The technology exists for inverter protection settings to be adjusted; some manually and others via remote communications. Note that major manufacturers that are in the international markets generally offer smart inverters with remote communications. However, new manufacturers continue to emerge, and they may not have these capabilities as they seek out niche markets that do not require smart inverters.

8.3. Industry Standard Development in Germany

There are several power systems in the world that are experiencing high solar penetration levels and/or growth. For example, the German power grid has a system peak of approximately 80 GW and is centrally located within their interconnection grid (*i.e.*, mainland Europe). Similar to New York, Germany is part of an interconnected grid and has moderate ties to its neighboring systems. Its renewable energy generation base includes about 40 GW of wind power and 40 GW of solar PV power and has a higher concentration of solar PV resources than New York. The wind power market is mature and has had to comply with a low voltage ride-through requirement since about 2008. The solar PV market expanded rapidly, growing by approximately 22.5 GW during the years 2010 through 2012. Market growth for both wind power and solar PV currently totals only about 3 to 5 GW per year. About 70% of the solar PV is connected at the low voltage level (*i.e.*, under 500V), where individual system sizes tend to range from 10 kW to 100 kW. The remaining installations are interconnected at distribution and transmission voltages with sizes ranging from roughly 1 MW at the low end to a maximum of 130 MW.

In Germany, all new large PV solar installations must meet a certification process, which includes ride-through requirements. The certification process includes device type tests, device model validation against type test results, and project analysis based on a project system model. No major system events have occurred in Germany involving solar PV, and it is believed that this is due to the implementation of ride-through standards "just-in-time." There was concern about the potential for a high-frequency event to cause unstable system dispatch due to dropout of the solar PV generation at the standard set point of 50.2 Hz (the European system operates at 50 Hz nominal, while North America operates at 60 Hz nominal). As a consequence, an enormous effort costing about $300 million and affecting 315,000 inverters was undertaken to change their high-frequency behavior to ramp the power output down as system frequency rose above 50.2 Hz.

8.4. Status of Standards

As stated before, the currently approved versions of IEEE 1547/1547a and UL 1741 do not permit ride through, but actually require and certify dropout for certain operating conditions. IEEE 1547 and UL 1741 currently are under revision to allow the Authority Having Jurisdiction (AHJ) to require ride through. However, these revisions are likely to take at least two more years before approved standards are in place. Even then, the AHJ has the discretion to require these features to be implemented.

In addition, on March 17, 2016, FERC issued a Notice of Proposed Rulemaking (NOPR), entitled "Requirements for Frequency and Voltage Ride Through Capability of Small Generating Facilities," in Docket No. RM16-8-000. The Commission proposes to revise the *pro forma* Small-Generator Interconnection Agreement to include a requirement for small generators (<20 MW) interconnecting with the transmission system to possess frequency and voltage ride-through capability.

In another regulatory development, on March 17, 2016, the New York Public Service Commission approved a proposal to increase from 2 MW to 5 MW the size of distributed generation subject to its Standardized Interconnection Requirements (SIR). The requirements that apply to generation connecting to the local utility's distribution system do not require ride-through capability for solar PV installations but do require facilities to be in compliance with applicable industry standards such as IEEE 1547 and UL 1741.

8.5. Findings and Recommendations

The lack of frequency and voltage ride-through requirements for solar facilities in New York could worsen system contingencies as solar PV deactivates in response to frequency and voltage excursions. It is therefore recommended that the NYISO comment to the FERC[12] and standard setting bodies such as IEEE in favor of adopting industry standards for solar inverter systems requiring voltage and frequency ride-through capabilities. It is further recommended that the NYISO request that the NYPSC and the NYTOs consider establishing voltage and frequency ride-through requirements on the non-bulk power system level.

[12] For example, the ISO/RTO Council has submitted comments to the NOPR in Docket No. RM-16-8-000 in support of the FERC's proposal to add frequency and voltage ride-through requirements to the *pro forma* Small Generator Interconnection Agreement.

9. Solar Integration Study Findings and Recommendations

This solar integration study addressed several important aspects of solar PV integration and makes several primary findings and recommendations:

- **The bulk power system can reliably manage over the five-minute time horizon the increase in net load variability associated with the solar PV and wind penetration levels studied (*i.e.* up to 4,500 MW wind and 9,000 MW solar PV).[13],[14]** As the penetration levels of solar PV and wind increase, any projected increases in regulation requirements are relatively minor and can readily be accommodated within the current market rules, transmission system operations, and generation resource mix. As noted, this overall finding is contingent upon the current resource mix and its capability to provide regulation services. To the extent that there is significant turnover in the NYCA fleet, this capability may be reduced. It is, therefore, recommended that the NYISO continue to track solar PV and wind penetration levels and the capability of its generation fleet to provide such services in order to assess and make adjustments, as appropriate.

- **The large-scale implementation of behind-the-meter solar PV will impact the NYISO's load profile and associated system operations.** Although such impacts may be mitigated to a degree and at some future date by the implementation of on-site electric storage technologies, it is recommended that the NYISO take action now to incorporate in its control room operations and markets real-time and day-ahead forecasts of solar PV output as soon as practicable.

- **The lack of frequency and voltage ride-through requirements for solar PV facilities in New York could worsen system contingencies when solar PV deactivates in response to frequency and voltage excursions.** It is, therefore, recommended that the NYISO comment to the Federal Energy Regulatory Commission (FERC) and standard setting bodies, such as IEEE, in favor of industry standards for solar inverter systems requiring voltage and frequency ride-through capabilities. It is also recommended that the NYISO request that the New York Public Service Commission (NYPSC) and the New York Transmission Owners (NYTOs) consider establishing ride-through requirements on the non-bulk power system level.

- **The experience of other regions undergoing similar growth in intermittent energy resources confirms the importance of monitoring the NYCA's capability to serve its regulation and ramping needs as wind and solar PV penetration increases and displaces conventional thermal generation.** The rapid growth of intermittent resources in other regions has had material impacts on

[13] All MW values for solar PV are denoted in DC capacity.

[14] The highest penetration values studied (*i.e.*, 9,000 MW of solar PV and 4,500 MW of wind) are not intended to reflect a ceiling for the integration of intermittent resources but are an achievable target in the next 5 to 15 years, assuming a reasonable amount of transmission can be built to interconnect the resources. Similarly, in its 2010 Wind Study the NYISO studied the impact on regulation requirements of up to 8,000 MW of wind which was considered to be the maximum achievable wind penetration within the time-frame studied.

the availability of essential reliability services such as frequency, voltage and system inertia. It is, therefore, recommended that the NYISO continue to study future requirements and the availability of such services as the level of intermittent resources increases, while maintaining existing market incentives for resources to remain flexible to real-time market conditions.

This study did not address a number of important questions pertaining to the large-scale integration of renewable resources into the New York system, including: the extent to which transmission constraints on the local distribution and bulk power systems may require expansion to accommodate the levels of wind and solar PV studied; the extent to which conventional generating resources could meet the additional multi-hour ramping requirements; and to what extent conventional fossil fuel generation would be displaced by the wind and solar PV resources coming online.

This study lays the groundwork for additional research underway at the NYISO. Such research will examine, among other aspects of system operations, the impact of compliance with pending environmental regulations on essential reliability service capabilities: voltage support, frequency control, and ramping. Furthermore, the integration of higher levels of renewable resource naturally leads to the examination of the benefits from additional investments in new or expanded transmission facilities to collect and transport energy from areas with abundant renewable resources to New York load centers. Fulfilling the Western New York and AC Transmission Public Policy Transmission Needs identified by the NYPSC, currently under study through the NYISO’s public policy transmission planning process, would add to the bulk power system’s ability to move renewable resources to load centers within New York.