# Solar Integration Study

## Draft Report of the NYISO 2015/2016 Solar Integration Study



Draft 6/7/2016

## 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, PSEG Long Island, and the New York Power Authority and is designed to result in 3,000 MW of installed PV capacity by 2024. 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. Specifically, this study has four primary areas of investigation:

- development of hourly solar profiles and a 15-year solar PV projection in the 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 to balance the system and maintain frequency and other key parameters in grid operations.

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

[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.

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.

Due to the variable nature and the uncertainty of renewable generation output, the patterns of solar PV and wind generation 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 solar integration study addressed several important aspects of solar PV integration and makes several primary findings and recommendations:

- **No bulk power system reliability issues are anticipated for solar PV and wind penetration levels studied (*i.e.* up to 4,500 MW wind and 9,000 MW (DC) solar PV).[2]** 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 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. Additionally, while not evaluated in this study, minor increases in regulation requirements may be further mitigated through the implementation of potential storage technologies or other measures within the State.

- **The large-scale implementation of behind-the-meter solar PV will impact the NYISO's load profile and associated system operations.** It is, therefore, recommended that the NYISO incorporate in its control room operations and markets real-time and day-ahead forecasts of solar PV output as soon as practicable.

[2] 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.

- **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 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 NYPSC and the 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 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 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 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 adds 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 and implementation of the NY-Sun Initiative (NY-Sun) is encouraging the development by 2024 of 3,000 MW (DC) or more of solar PV generation in the New York Control Area (NYCA). Significant increases in solar PV penetration have already been experienced since the initiation of NY-Sun. A total of 314 MW (DC) of solar electric was installed as of December 2014 statewide. By 2015, over 500 MW (DC) of small- and large-scale behind-the-meter solar PV installations were located in the NYCA, representing an increase of about 63% over 2014 levels. 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.

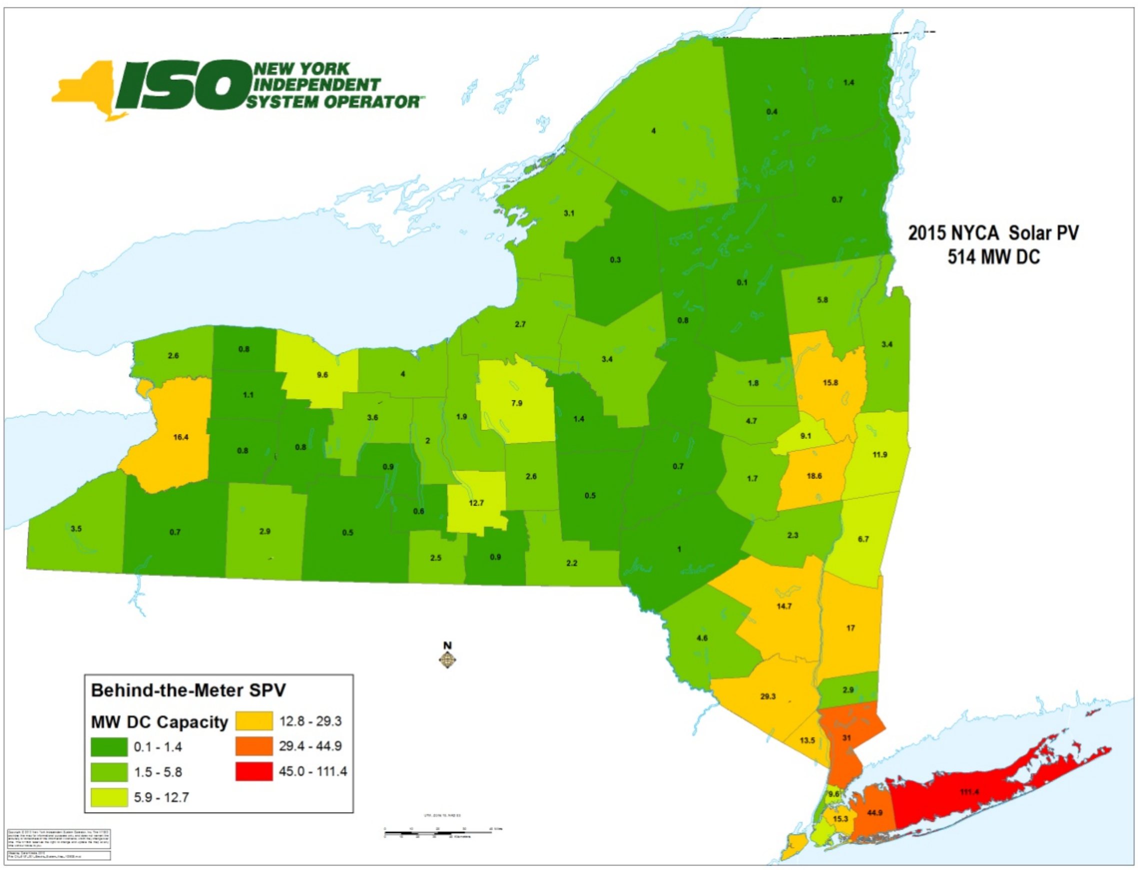


Figure 1-1: Heat Map of Behind-the-Meter Solar in 2015

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.

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.

## 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 (DC) of behind-the-meter solar PV installations to as much as 9,000 MW (DC) 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. 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 (in DC MW) by NYCA zone through 2030. For comparison purposes, the table also includes zonal distributions for projections of 4,500 MW (DC), 6,000 MW (DC), and 9,000 MW (DC) by 2030. The latter values were the scenarios studied as part of the regulation requirement evaluation in Task 4.

Table 3-1: Solar Capacity (DC MW) 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.

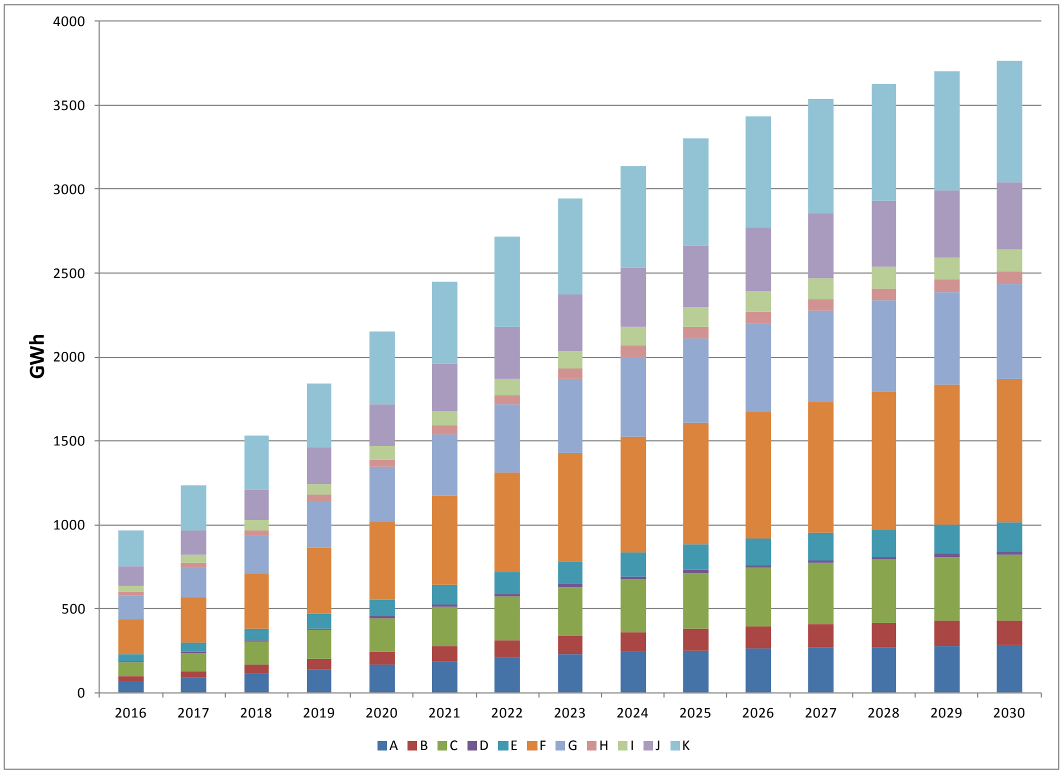


Figure 3-1: Energy Impacts by Year

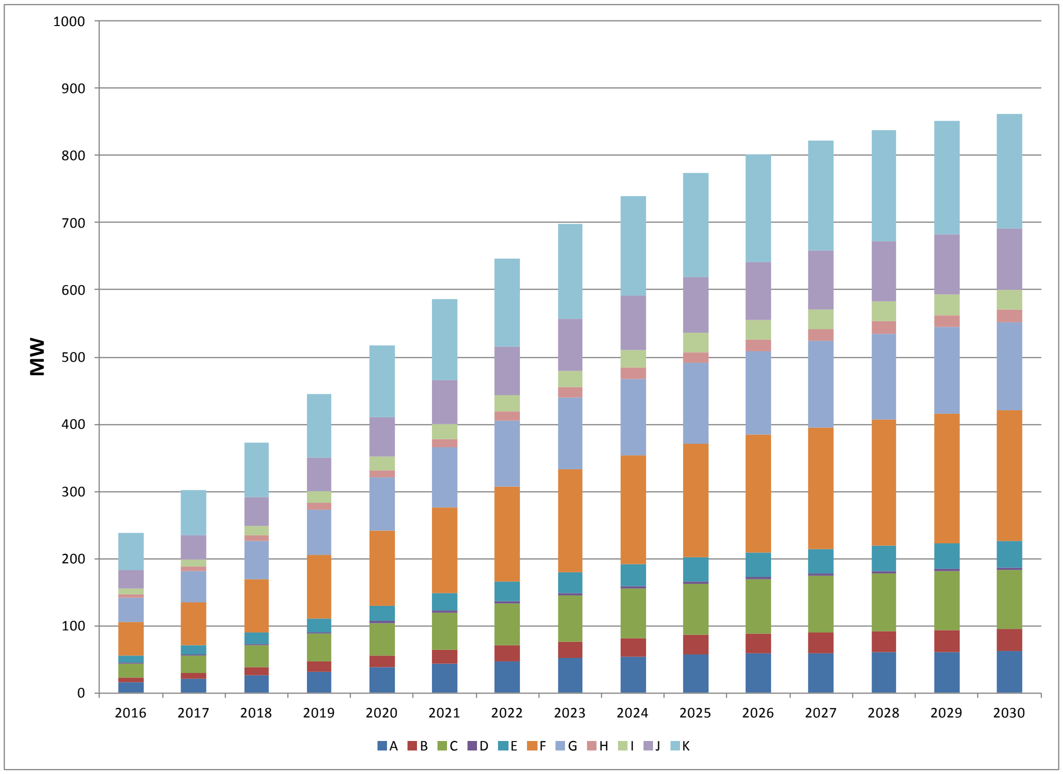


Figure 3-2: Peak Load Impacts by Year

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.

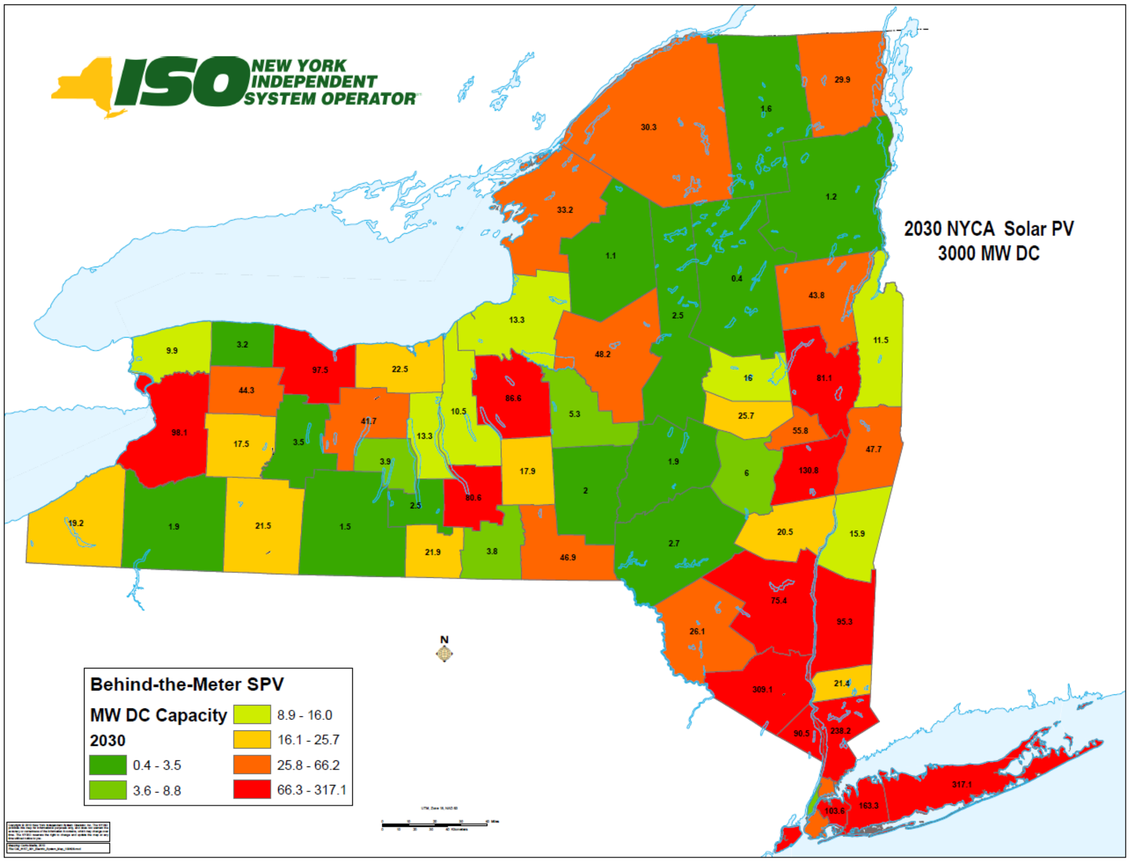


Figure 3-3: Heat Map of Behind-the-Meter Solar PV by 2030

## 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 8760 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. 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.

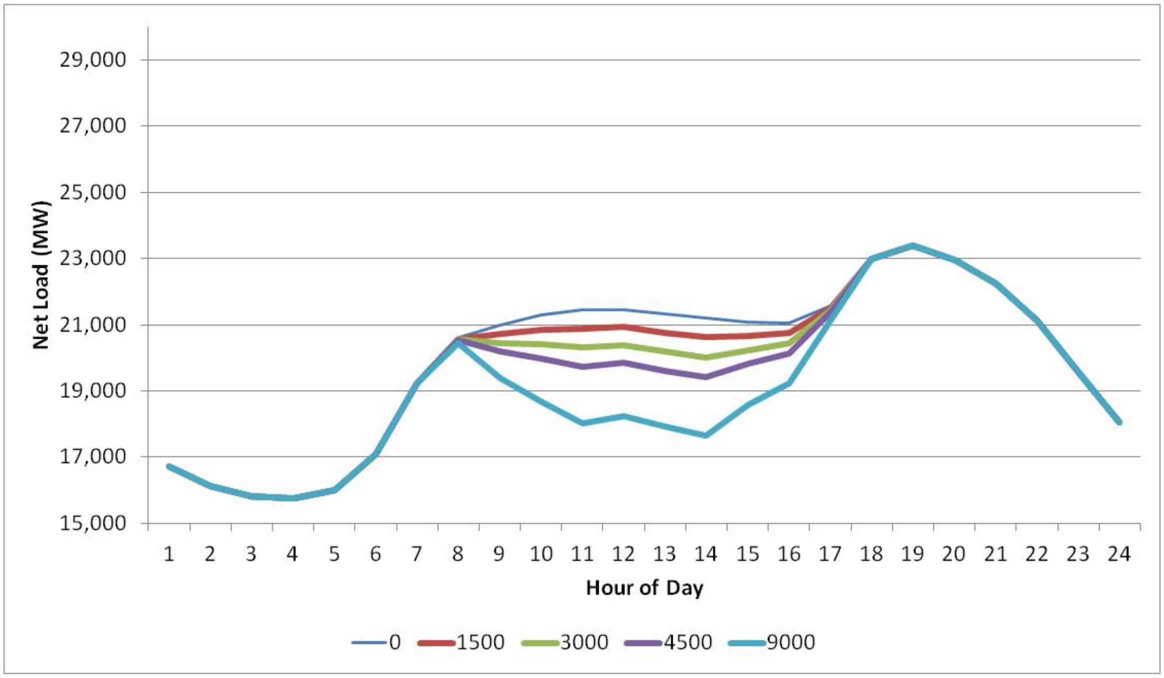


Figure 3-4: Typical Winter Day: Levels of Solar Penetration

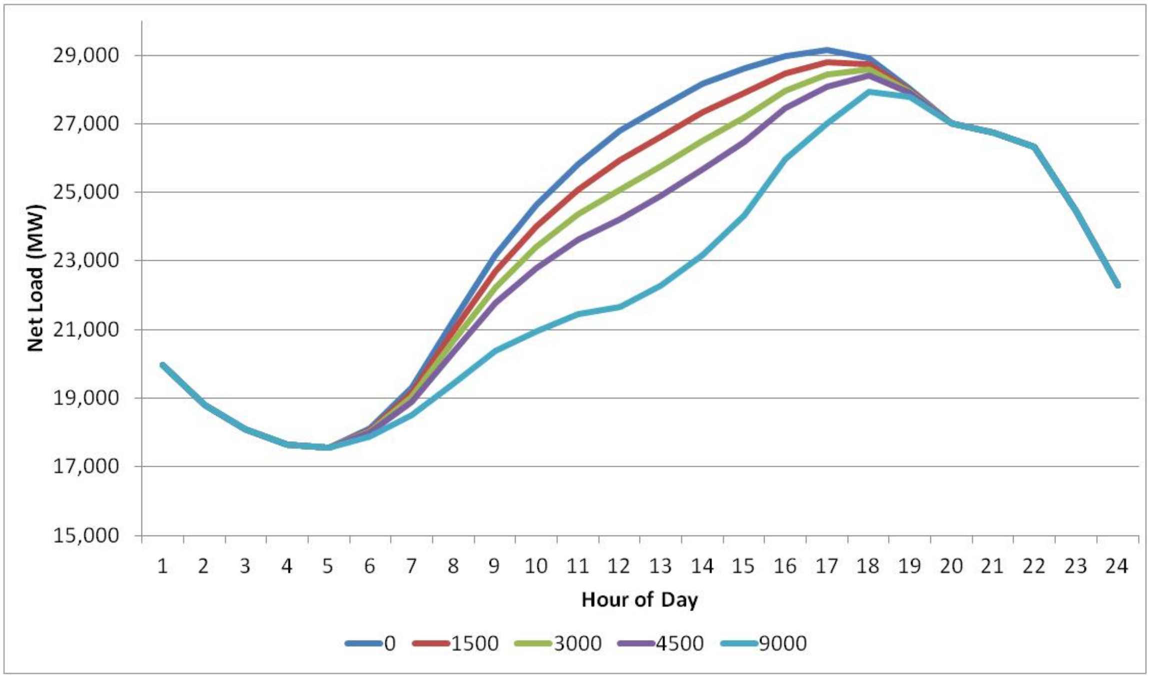


Figure 3-5: Typical Summer Day: Levels of Solar Penetration

# 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.

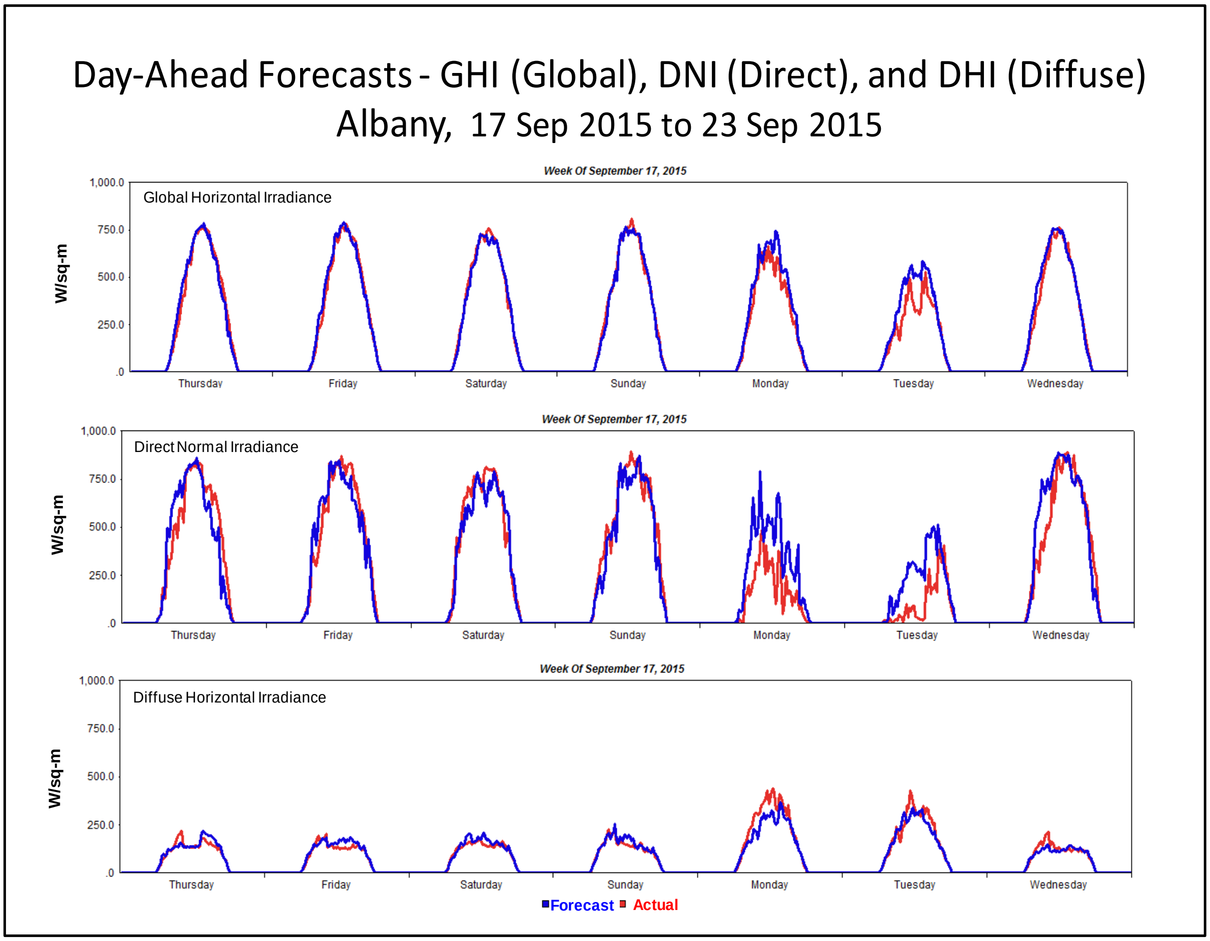


Figure 4-1: Forecasts of Irradiance During a Week in September

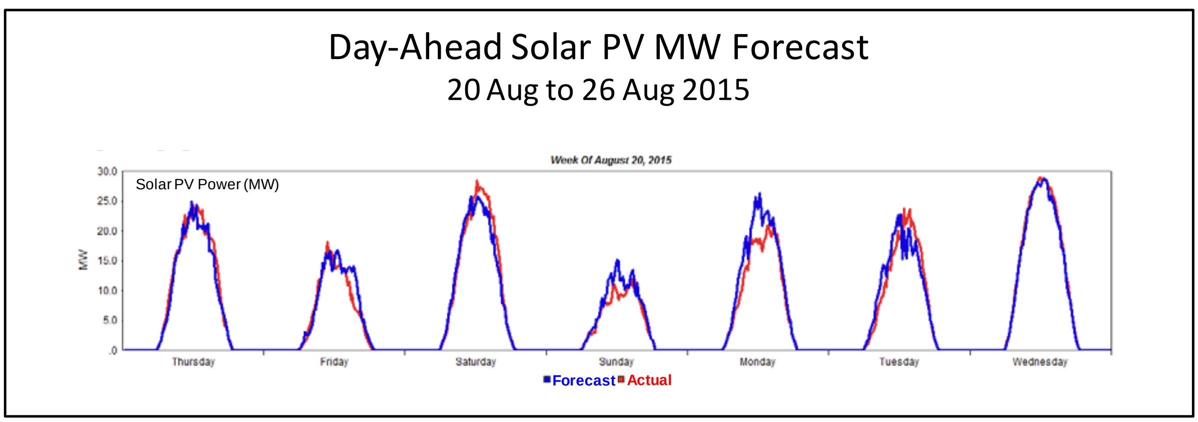


Figure 4-2: Forecasts of Solar Power During a Week in August

# 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[3]

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 lead 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. The

[3] 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.

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[4]

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 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

[4] 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.

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.

## 5.3. PJM[5]

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 compared to the roughly 1,200 MW of regulation 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,
- 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:

[5] Sources for the PJM experience, include: *PJM Renewable Integration Study*, PJM Interconnection, LLC, November 2012.

- 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.

## 5.4. GERMANY[6]

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

## 5.5. ONTARIO, CANADA[7]

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.

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[6] Sources for the German experience, include: (a) *A Tale of Three Ma*rkets, *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.

[7] 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.

- 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 storage, and
- Specific attention needs to be paid to the level of essential reliability services on the grid—inertia, frequency, and voltage support, and
- 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 and one day in which there was a minimal amount of 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 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 current installed capacity of behind-the-meter solar PV.

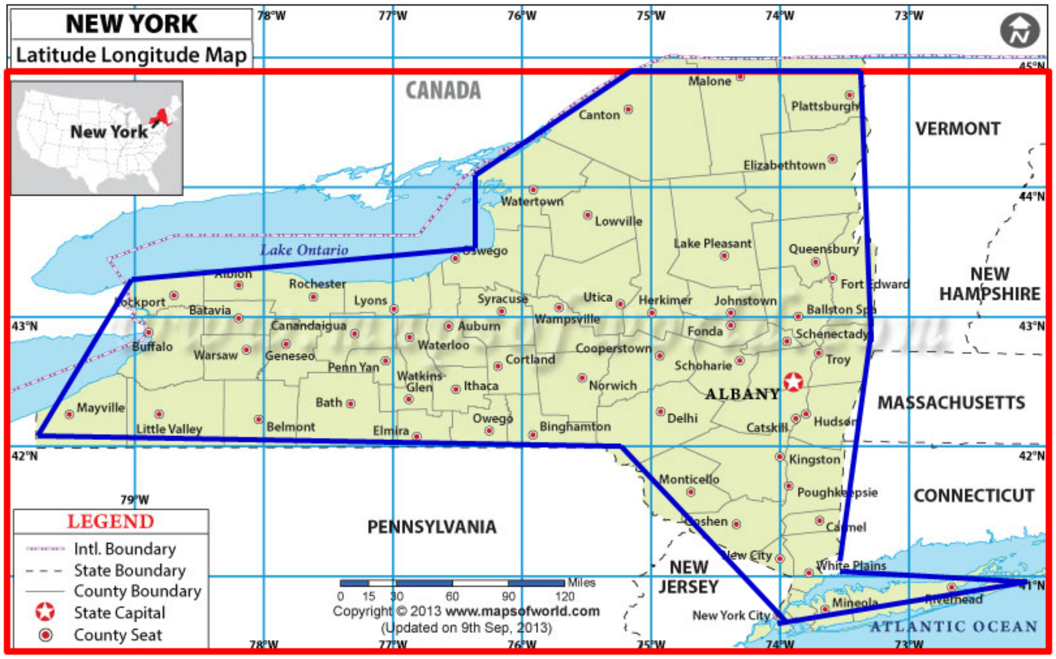


Figure 6-1: Rectangular Area for Which Solar Backcast for 2006 Was Obtained

The result is a spatial and temporal database representative of current 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 (DC). Also included are total load and net load (*i.e.*, load less solar PV).

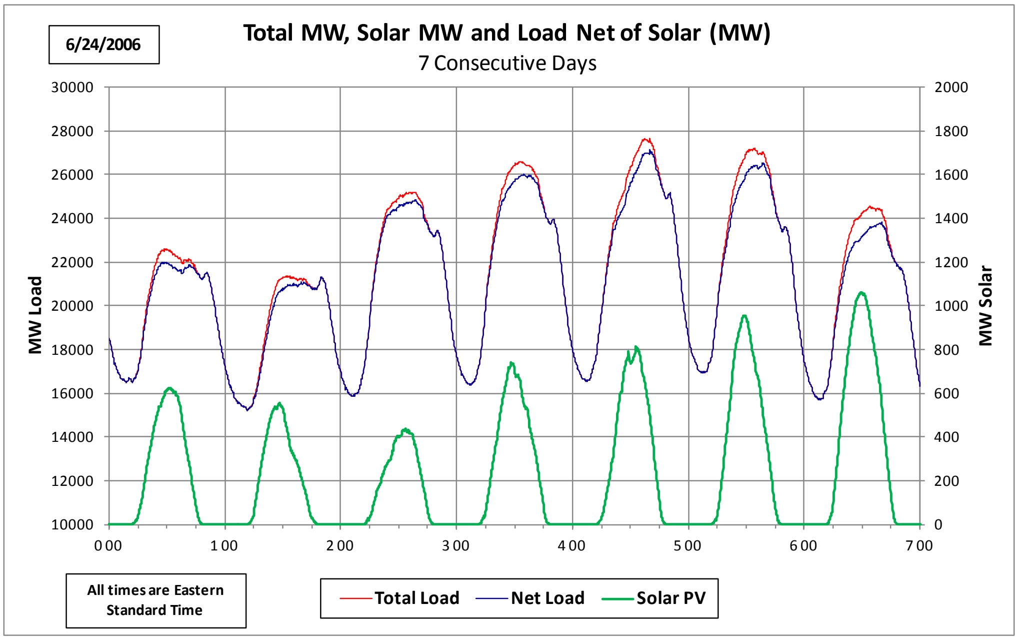


Figure 6-2: Solar PV, Total Load and Net Load for a 7-day Period

As presented in Table 6-1, three study scenarios of statewide solar potential were selected as follows: (1) 1,500 MW (DC) solar PV plus 2,500 MW wind for the year 2019; (2) 3,000 MW (DC) solar PV plus 3,500 MW wind for the year 2024; and (3) either 4,500 MW (DC) or 9,000 MW (DC) 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 solar and wind resources above current levels in three scenarios at various levels of penetration, ranging up to 9,000 MW (DC) 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

| | Wind | | Solar | |
|---|---|---|---|---|
| Scenario | 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 dispatchability. 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:

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

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

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

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.

## 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:[8]

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 |

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

## 7.2. Scenario 1

Results from Scenario 1 (2,500 MW wind and 1,500 MW (DC) 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 (DC) level. Note that regulation requirements are 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.

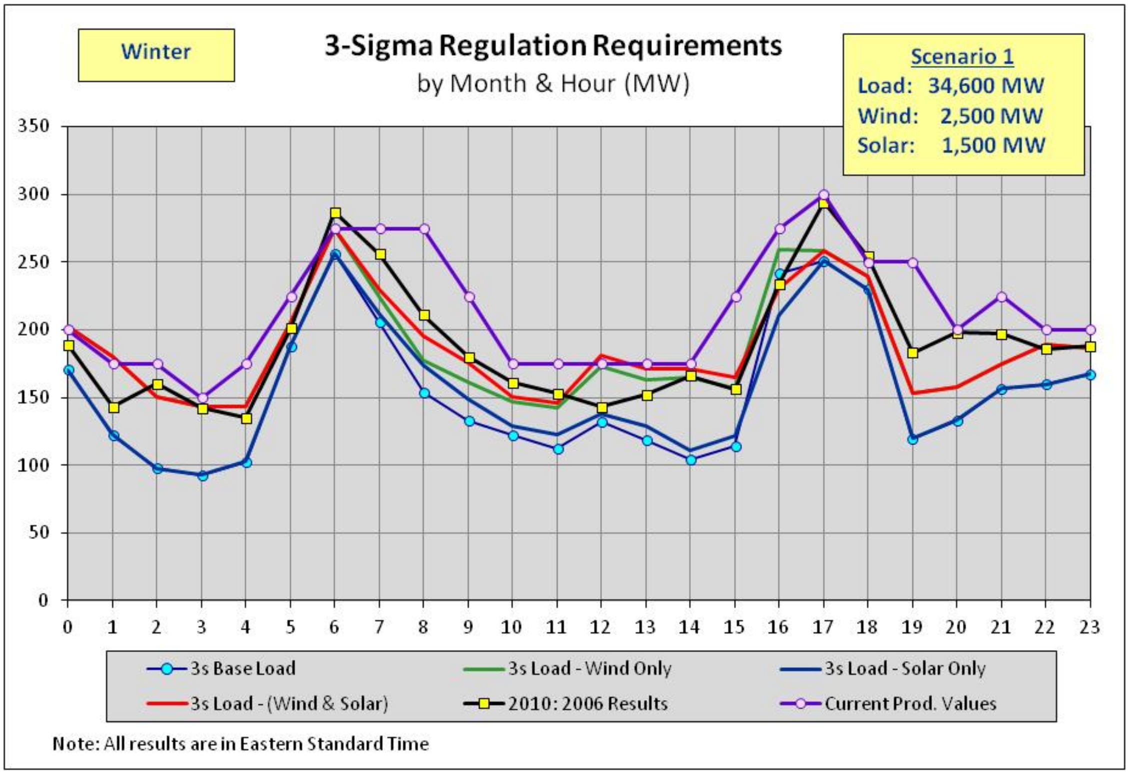


Figure 7-2: Scenario 1 Winter Regulation Results

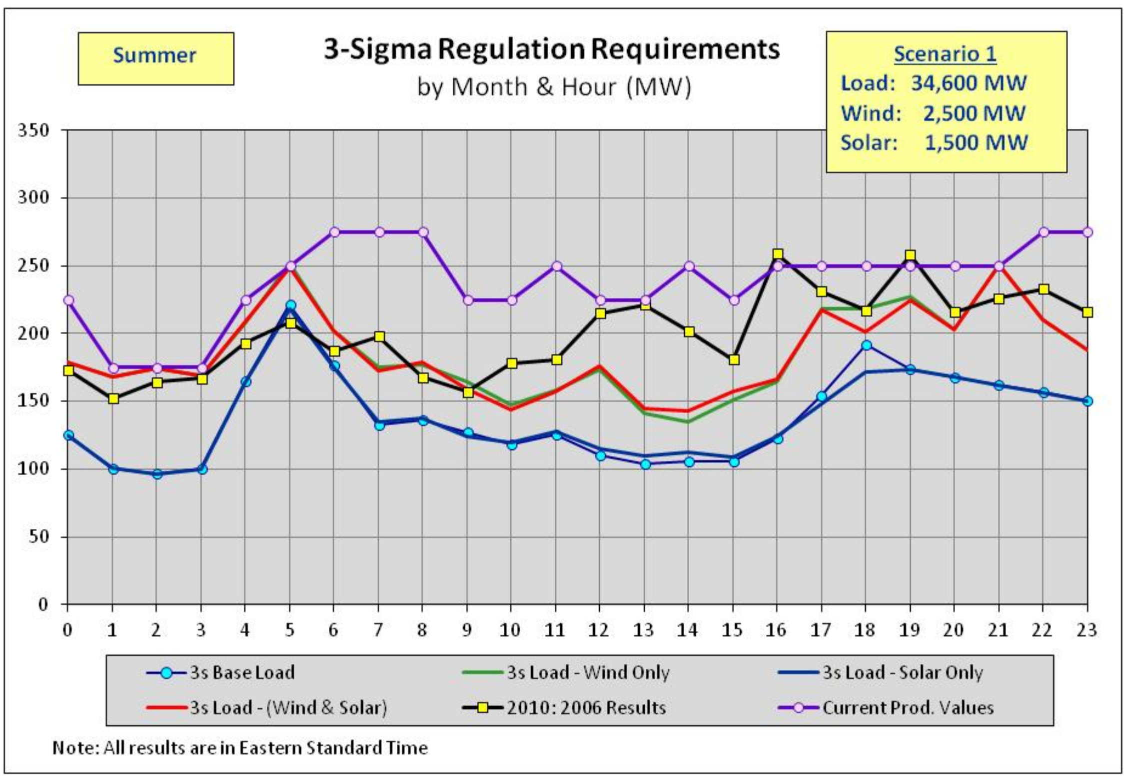


Figure 7-3: Scenario 1 Summer Regulation Results

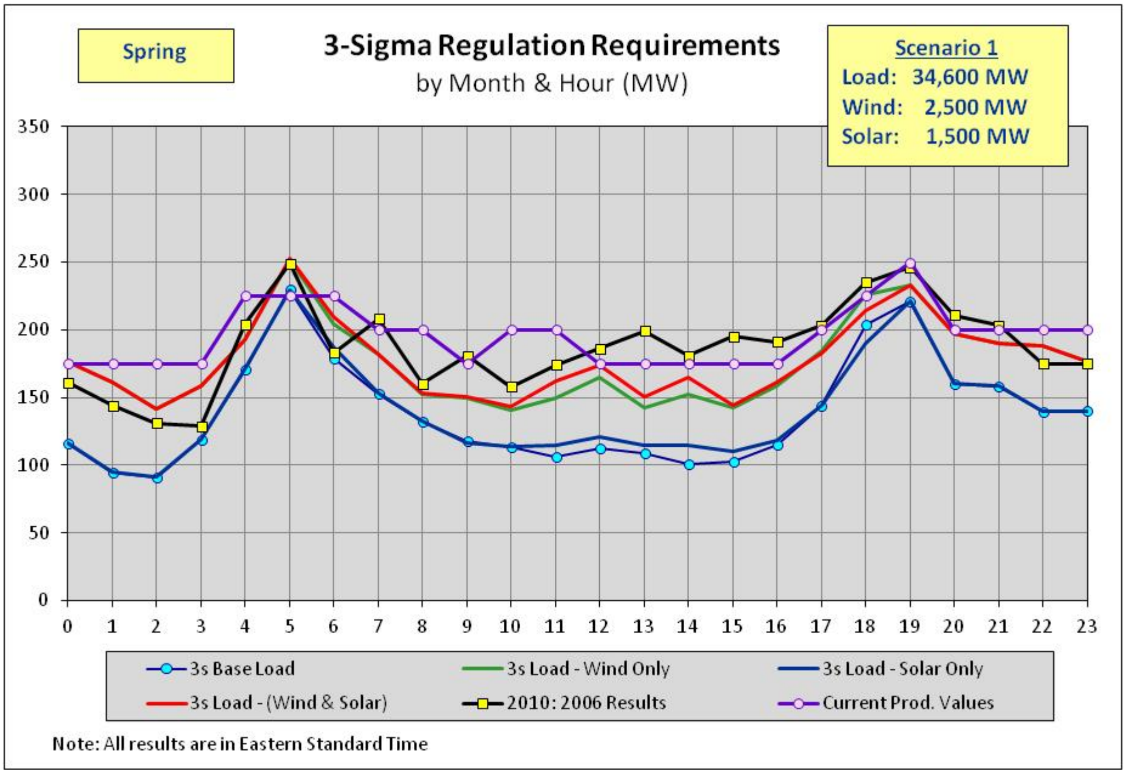


Figure 7-4: Scenario 1 Spring Regulation Results

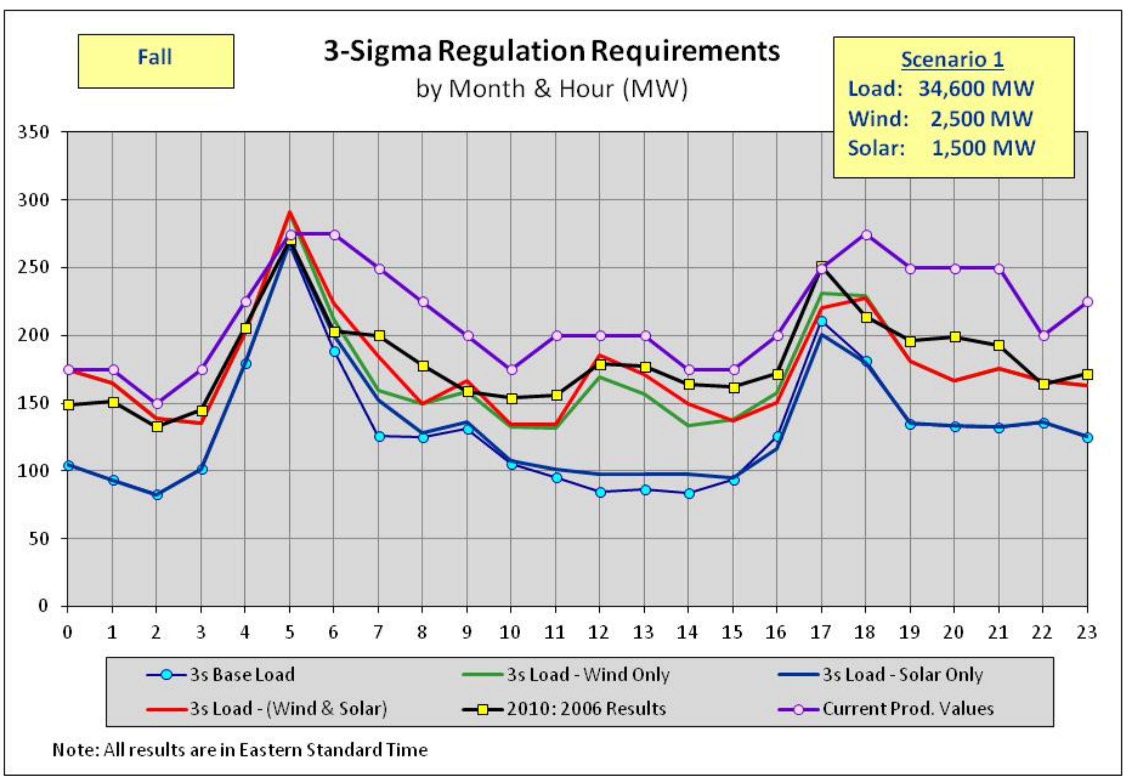


Figure 7-5: Scenario 1 Fall Regulation Results

## 7.3. Scenario 2

Results from Scenario 2 (3,500 MW wind and 3,000 MW (DC) solar PV) indicate that as the integration of intermittent resources on the system surpasses 1,500 MW (DC) 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.

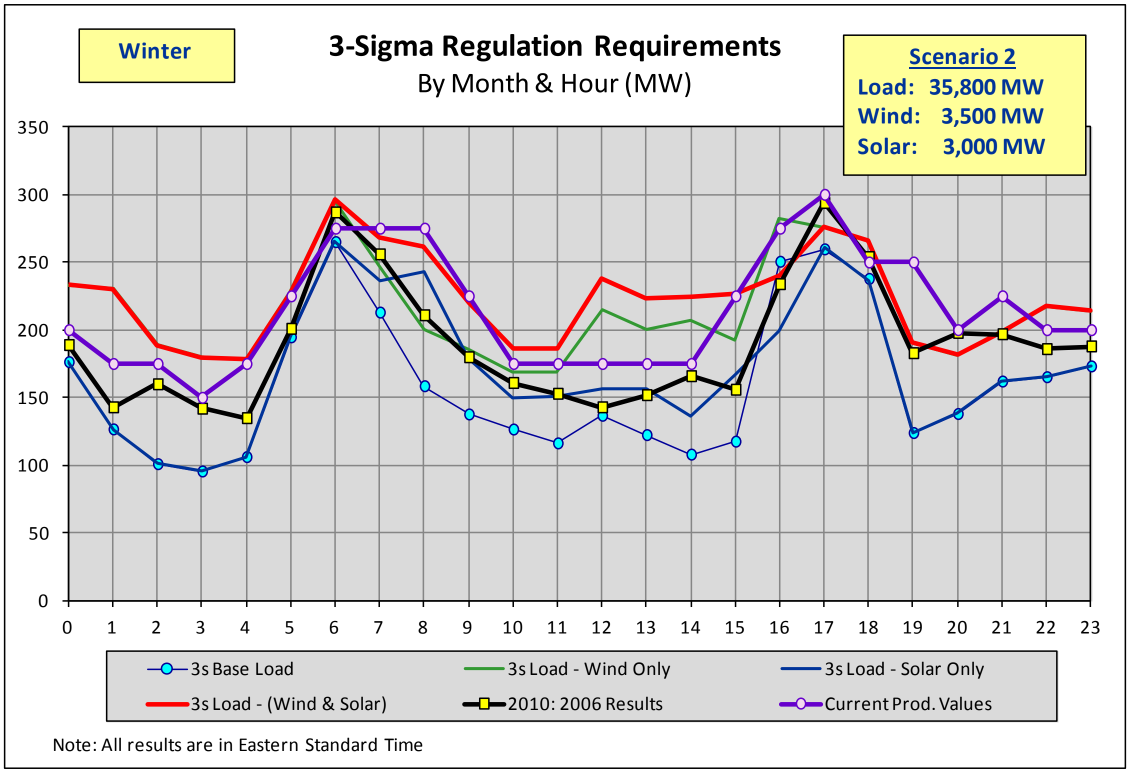


Figure 7-6: Scenario 2 Winter Regulation Results

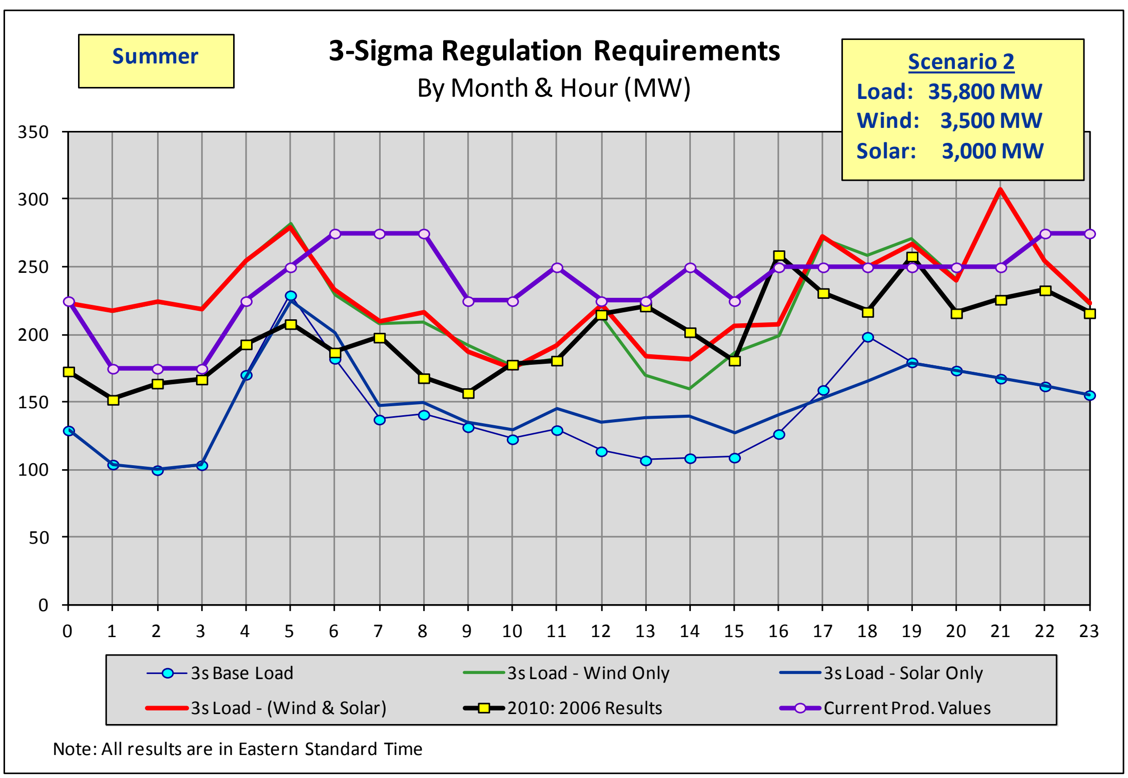


Figure 7-7: Scenario 2 Summer Regulation Results

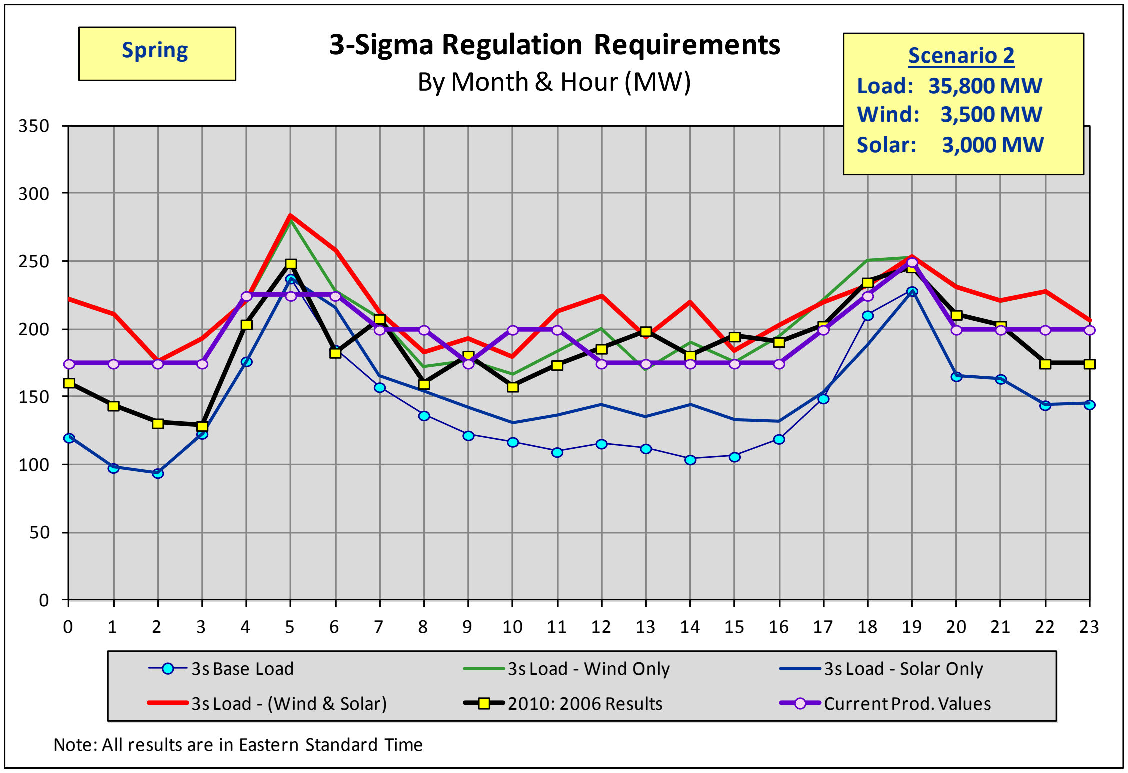


Figure 7-8: Scenario 2 Spring Regulation Results

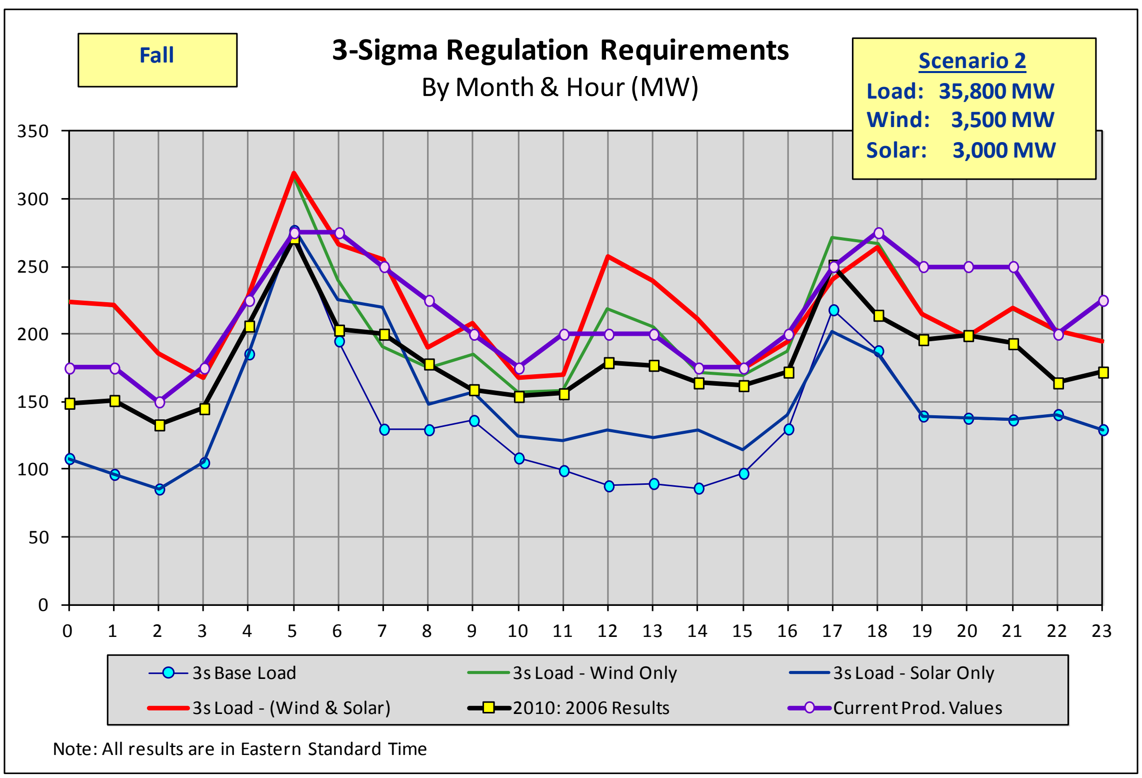


Figure 7-9: Scenario 2 Fall Regulation Results

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<br>2024<br>3,500 MW Wind<br>3,000 MW Solar | June - August<br>2024<br>3,500 MW Wind<br>3,000 MW Solar | September - October<br>2024<br>3,500 MW Wind<br>3,000 MW Solar | November - March<br>2024<br>3,500 MW Wind<br>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.

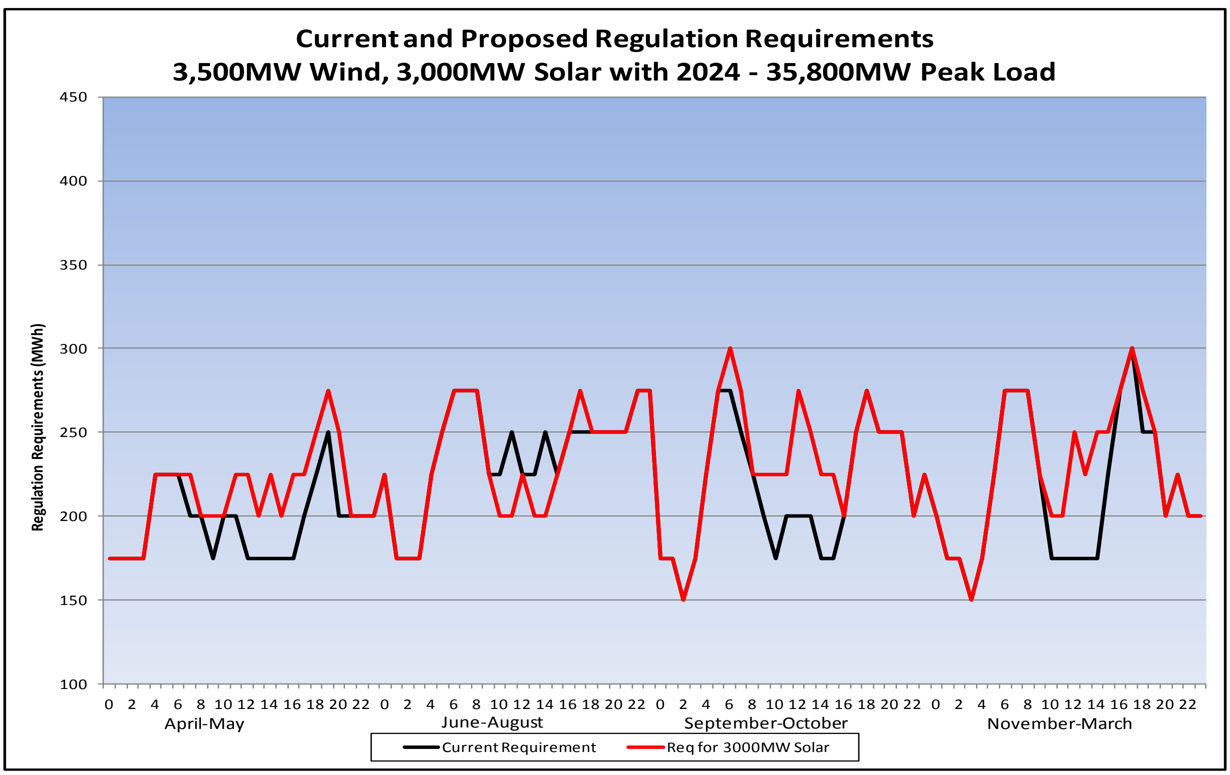


Figure 7-10: Comparison of Scenario 2 to Current Requirements

## 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 (DC) to 9,000 MW (DC). NYISO Operations performed an abbreviated analysis of these scenarios and determined that an increase of 1,500 MW (DC) 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 (DC) to 9,000 MW (DC) 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 |

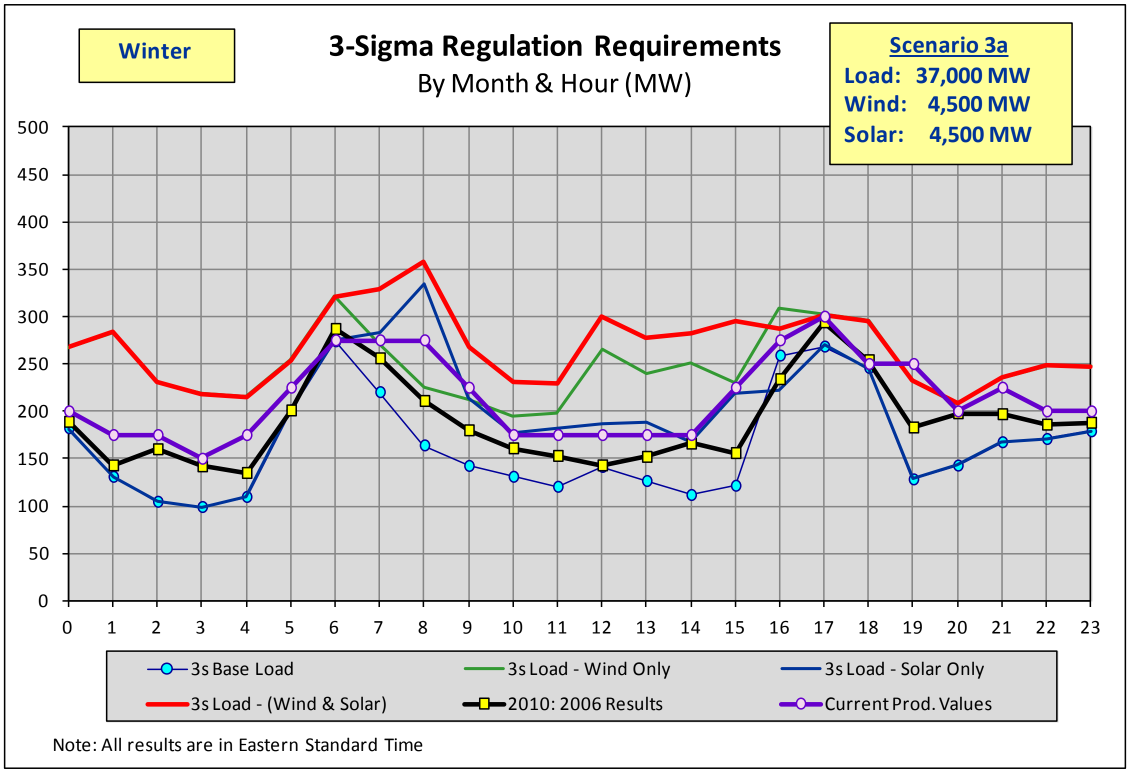


Figure 7-11: Scenario 3a Winter Regulation Results

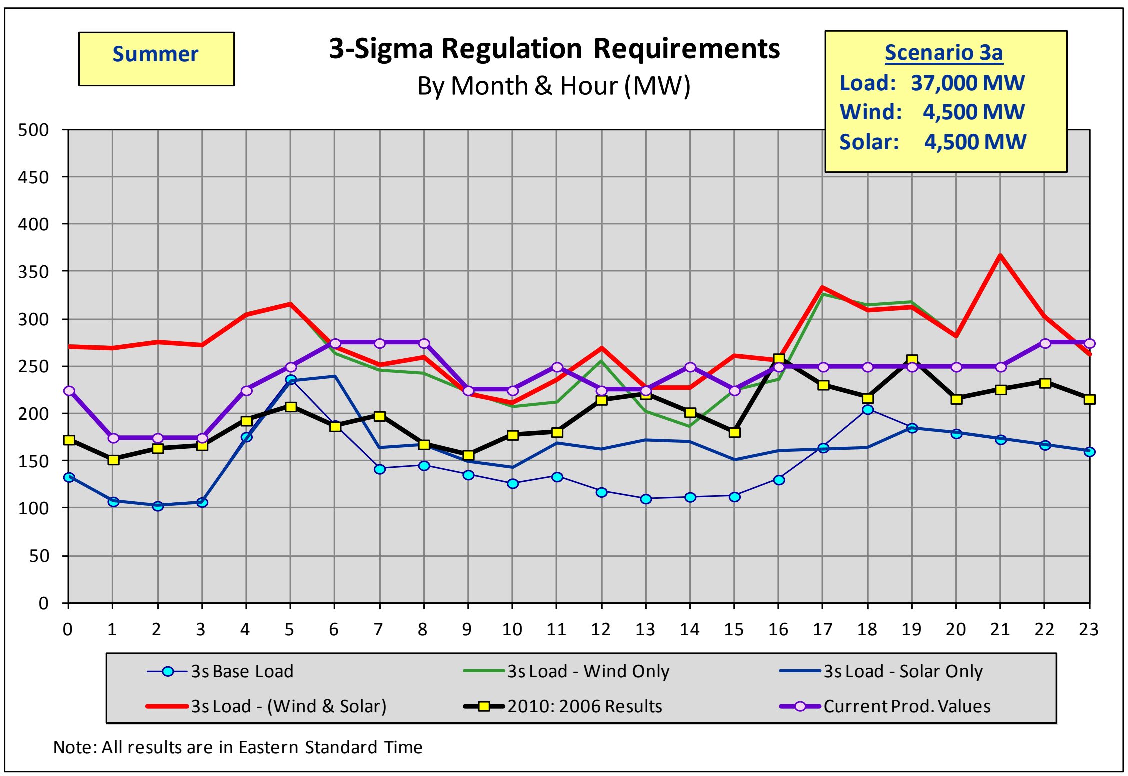


Figure 7-12: Scenario 3a Summer Regulation Results

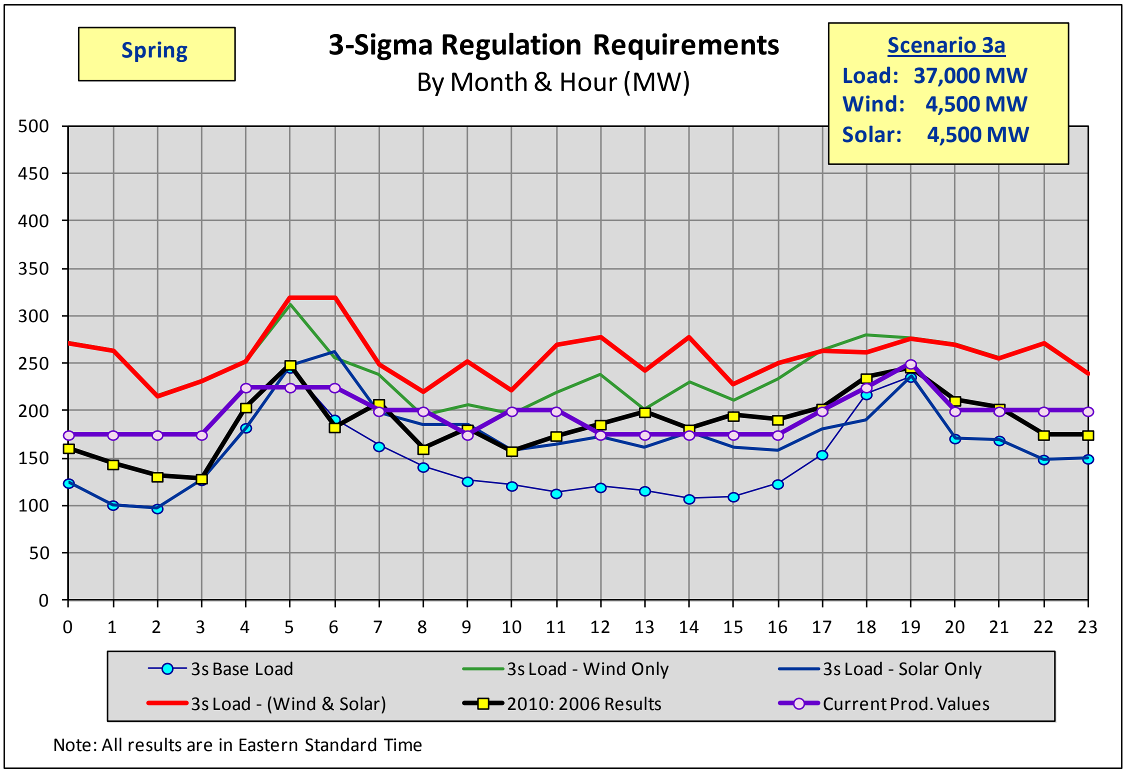


Figure 7-13: Scenario 3a Spring Regulation Results

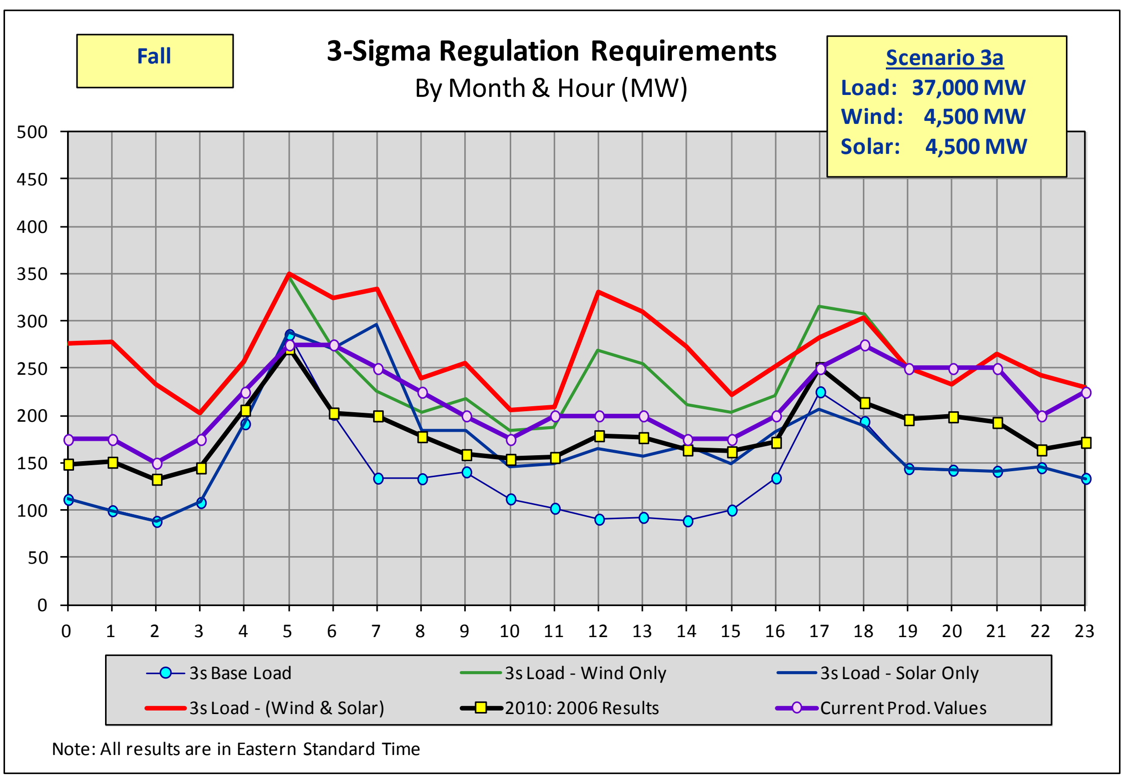


Figure 7-14: Scenario 3a Fall Regulation Results

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

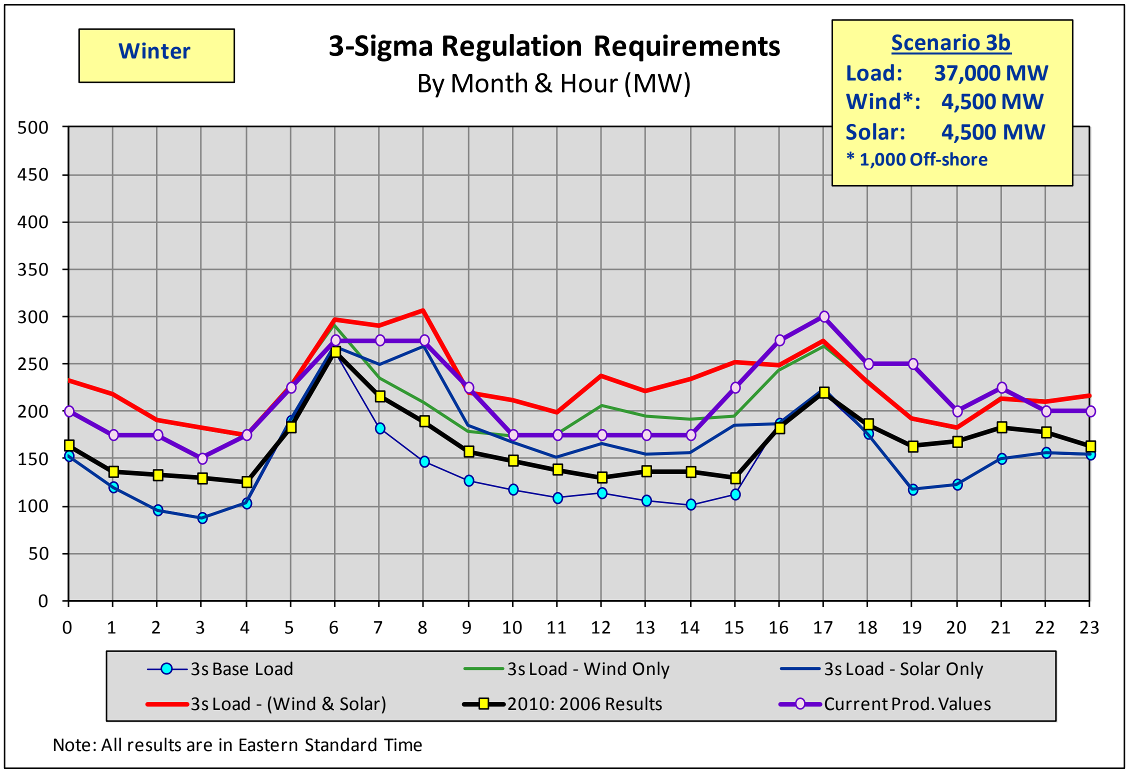


Figure 7-15: Scenario 3b Winter Regulation Results

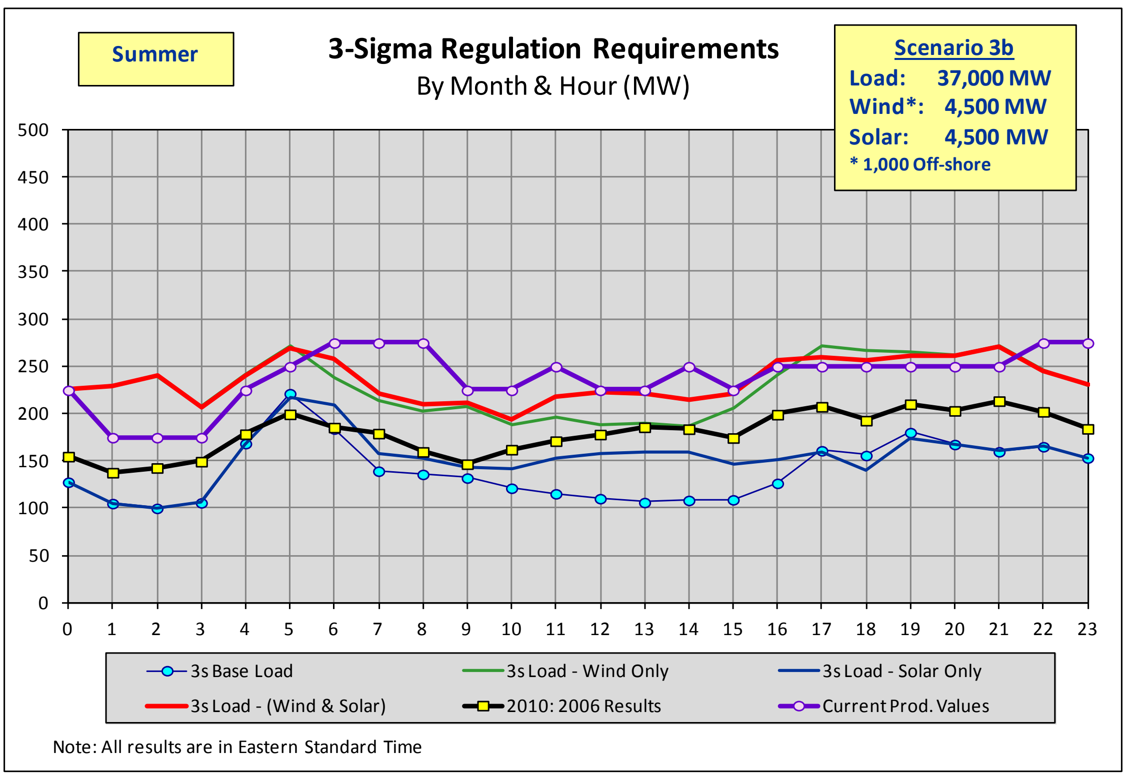


Figure 7-16: Scenario 3b Summer Regulation Results

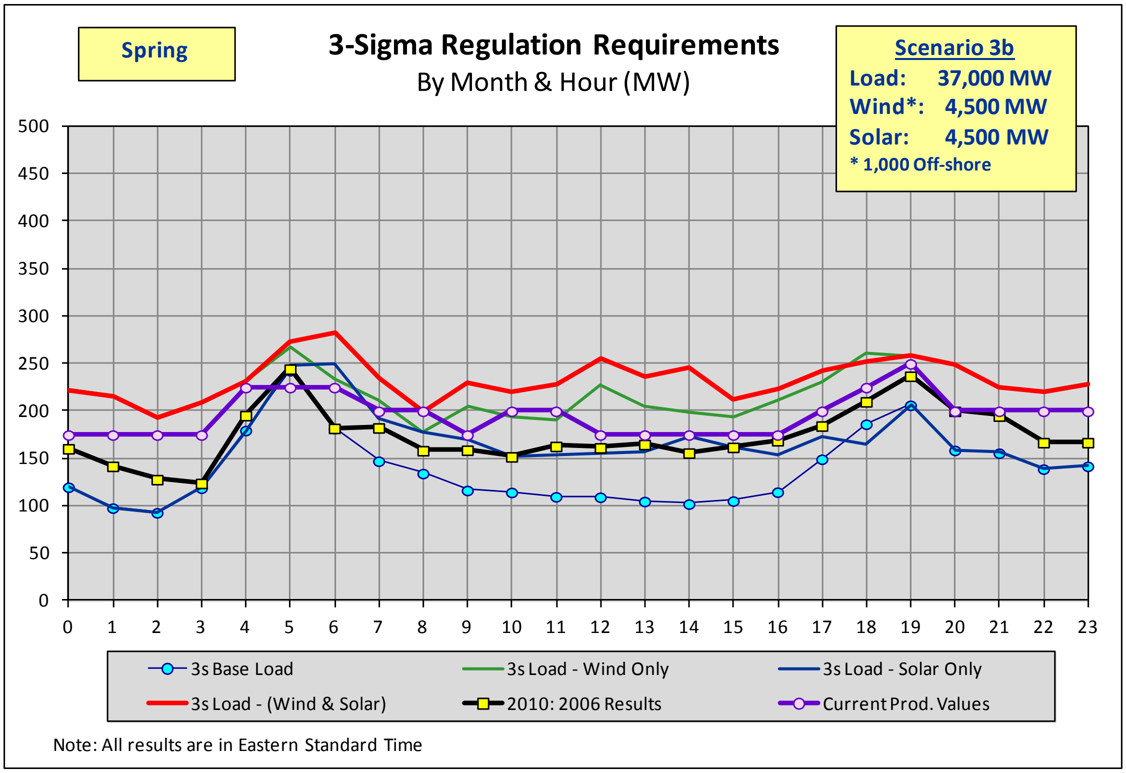


Figure 7-17: Scenario 3b Spring Regulation Results

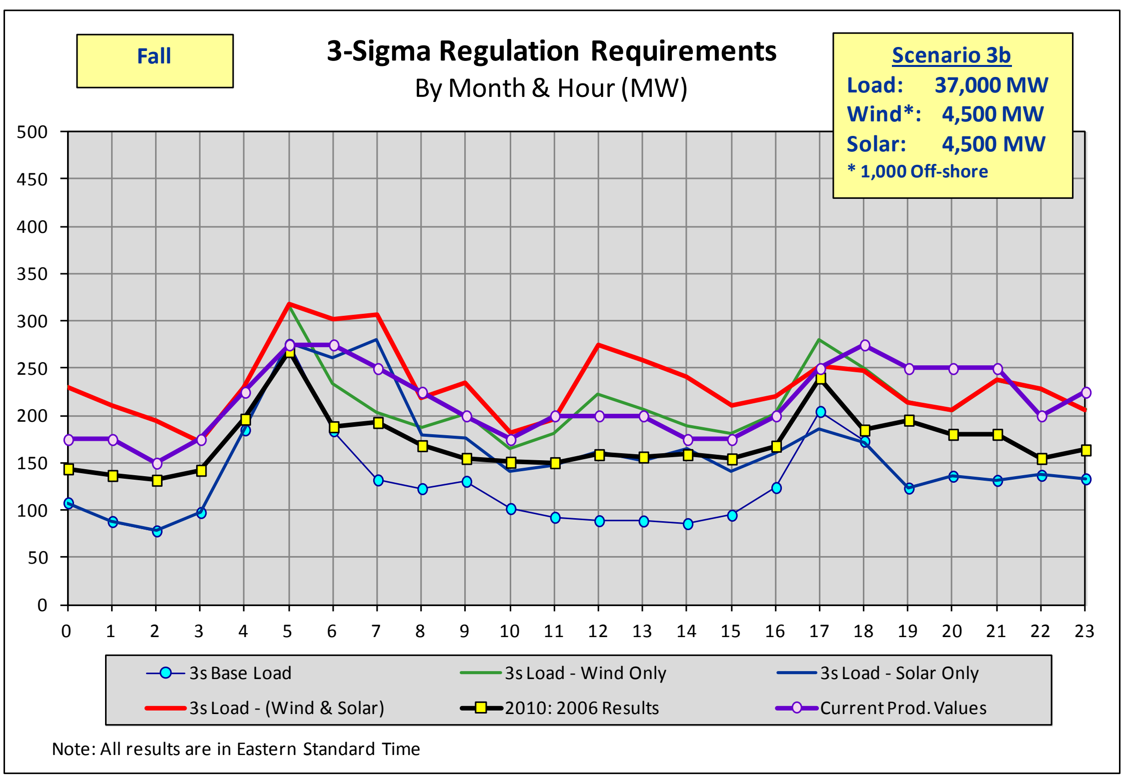


Figure 7-18: Scenario 3b Fall Regulation Results

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.

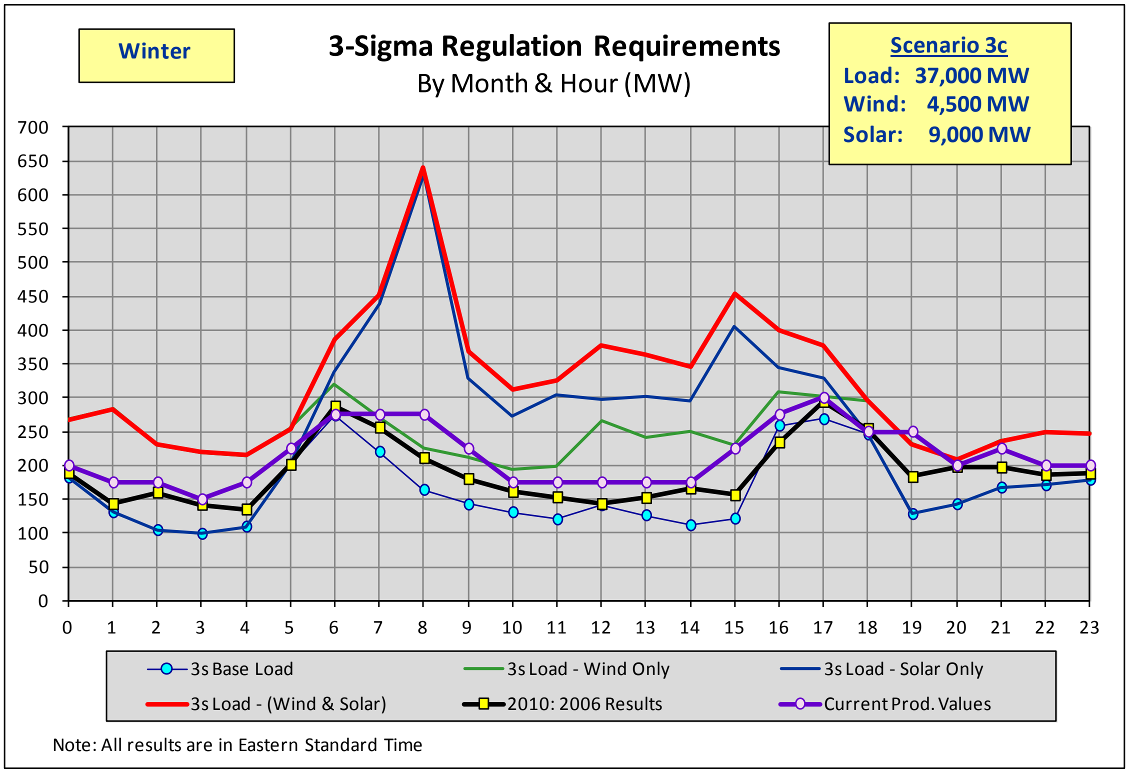


Figure 7-19: Scenario 3c Winter Regulation Results

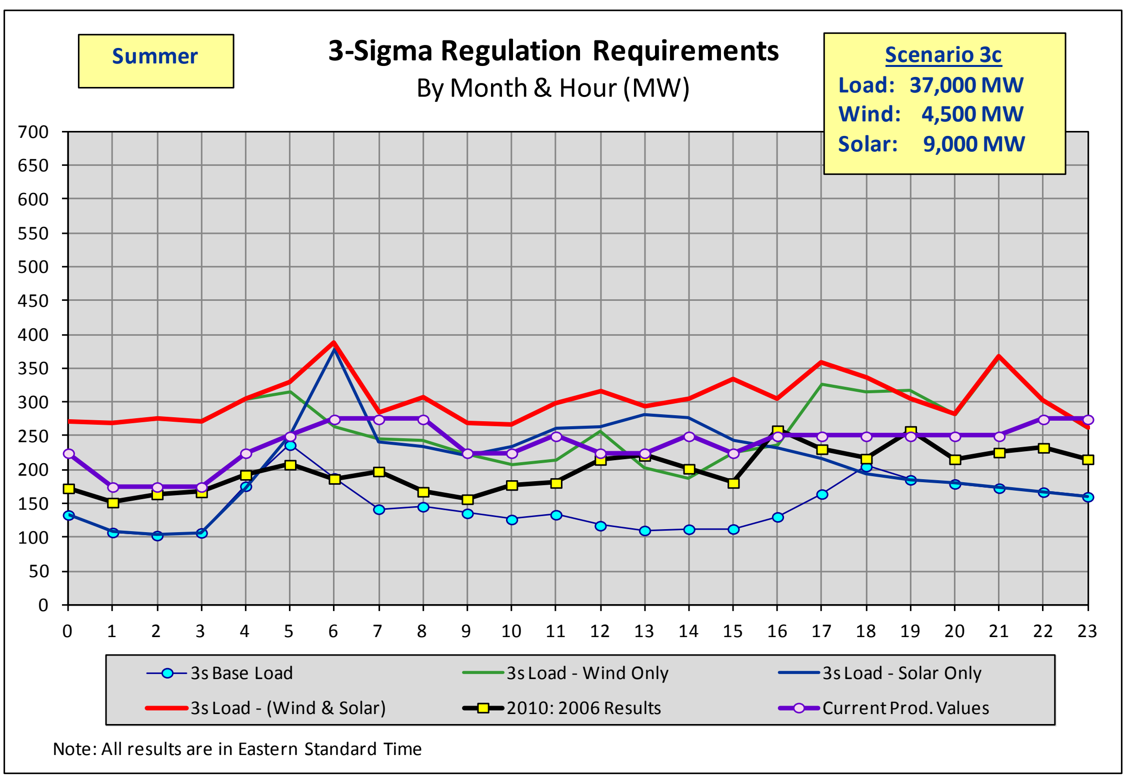


Figure 7-20: Scenario 3c Summer Regulation Results

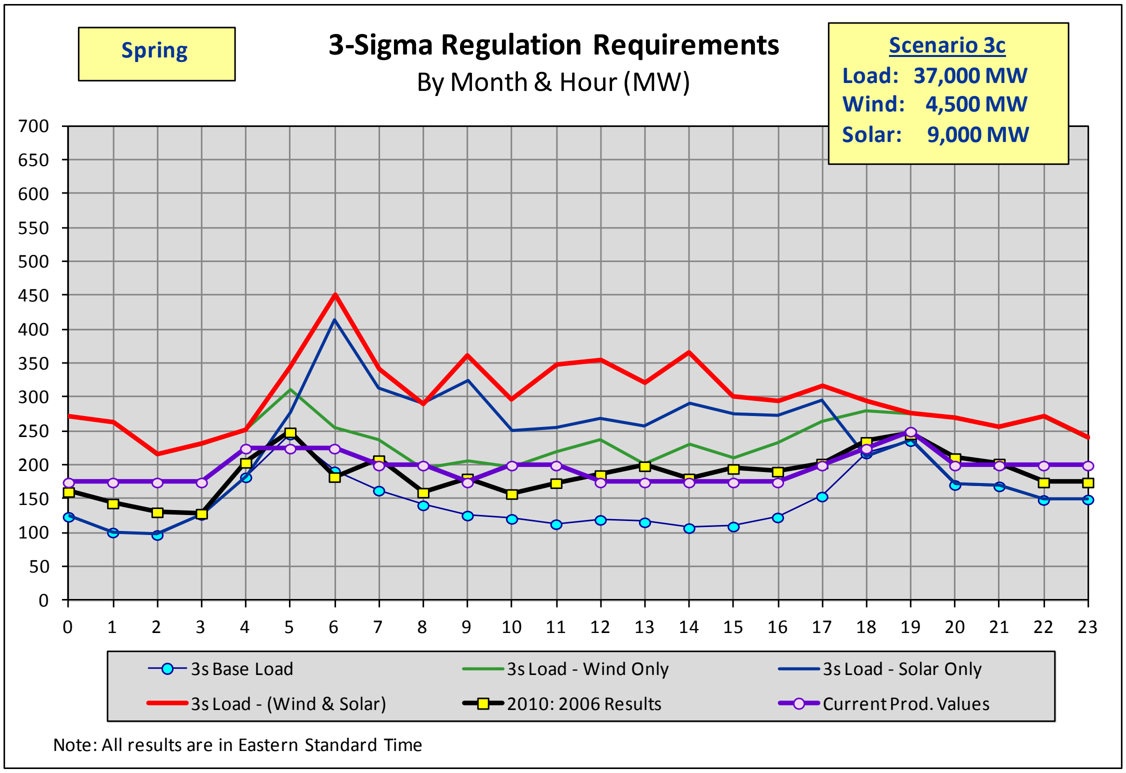


Figure 7-21: Scenario 3c Spring Regulation Results

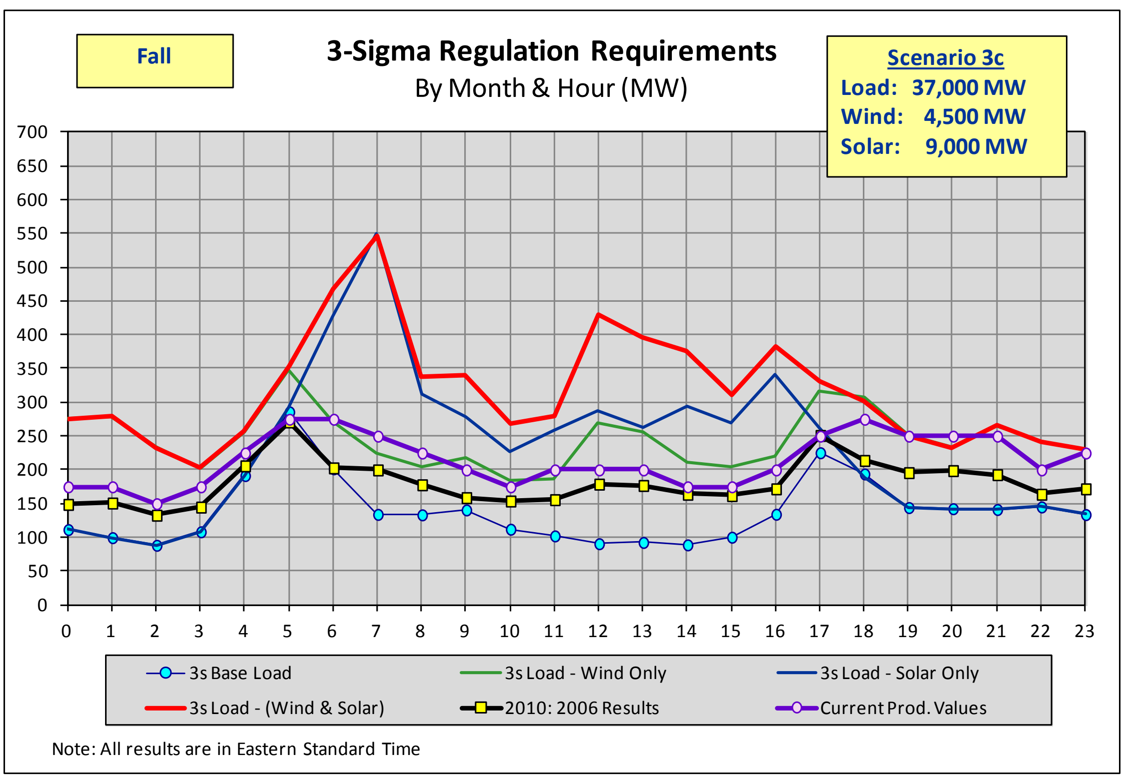


Figure 7-22: Scenario 3c Fall Regulation Results

## 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

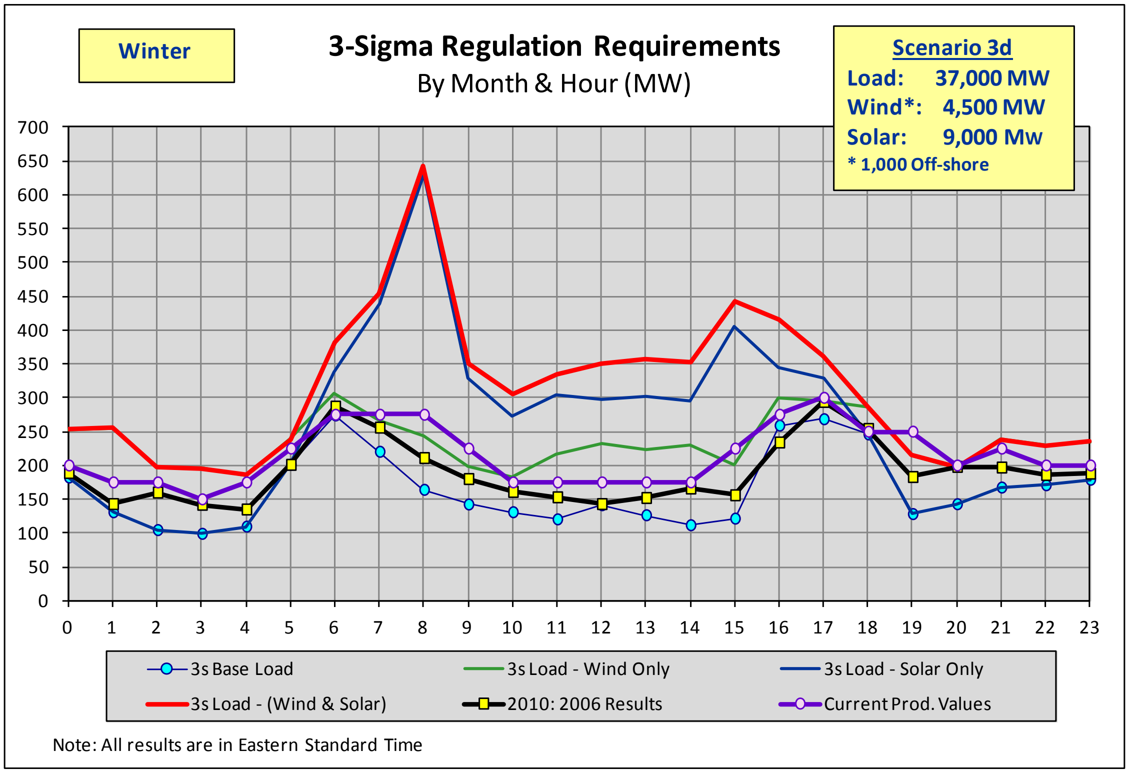


Figure 7-23: Scenario 3d Winter Regulation Results

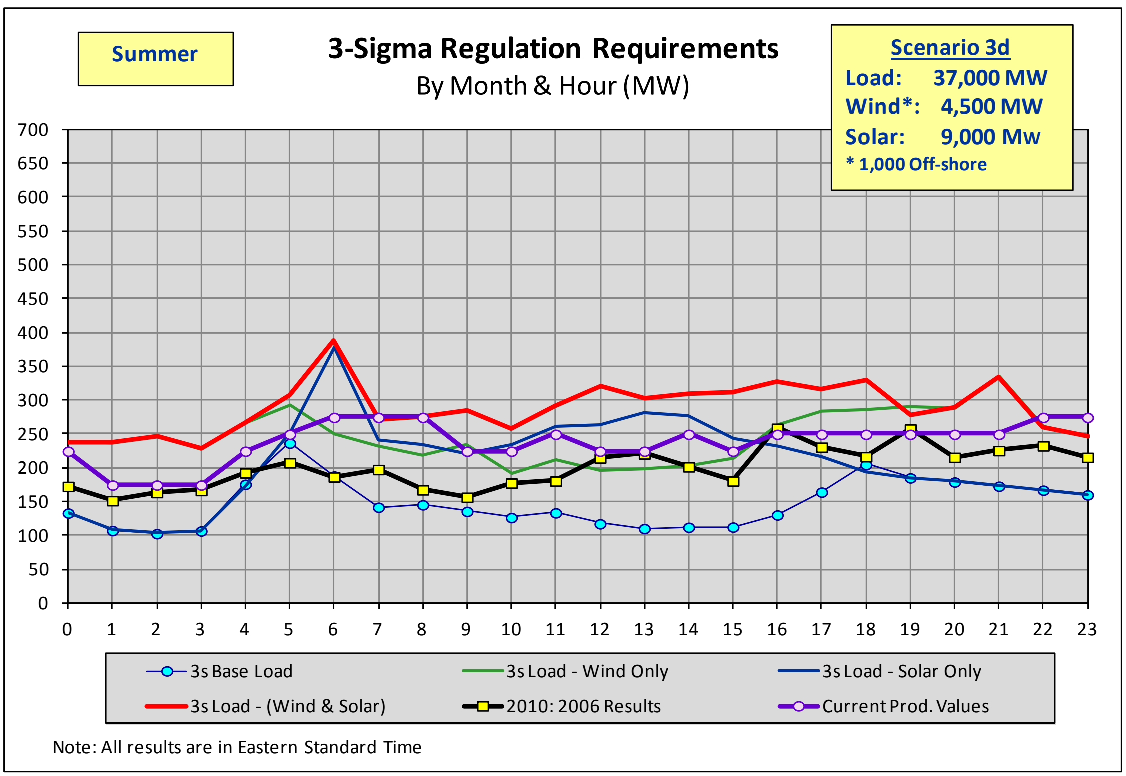


Figure 7-24: Scenario 3d Summer Regulation Results

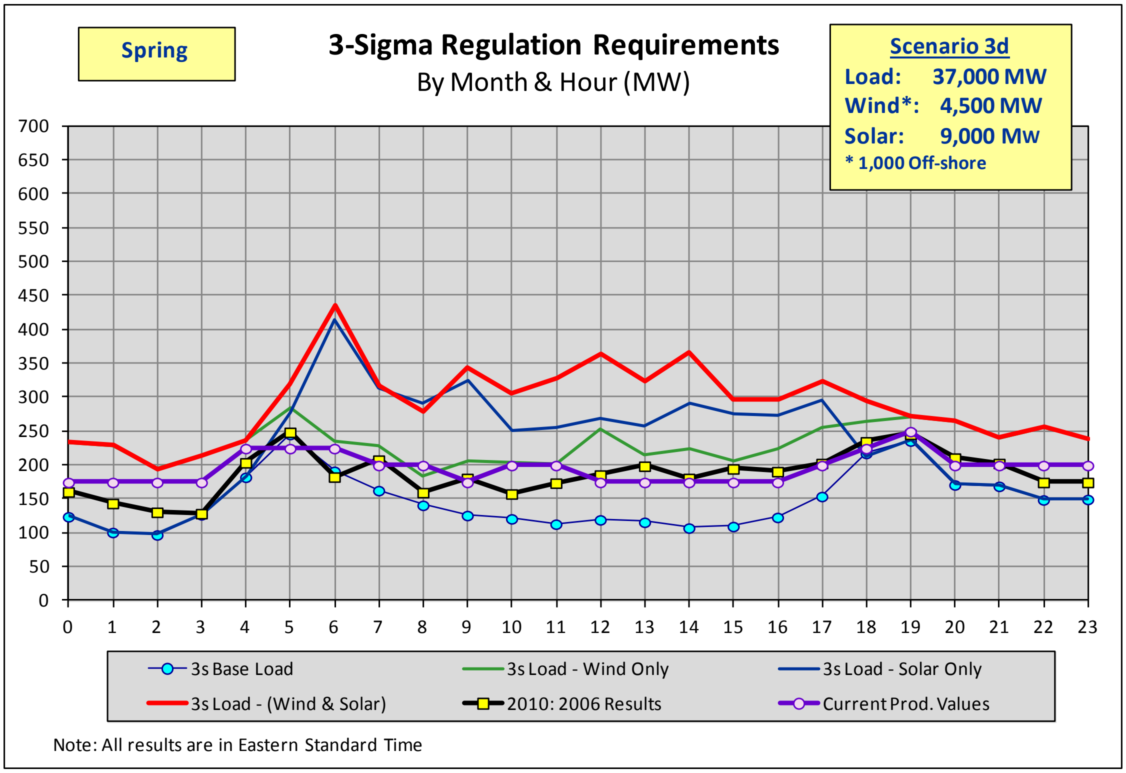


Figure 7-25: Scenario 3d Spring Regulation Results

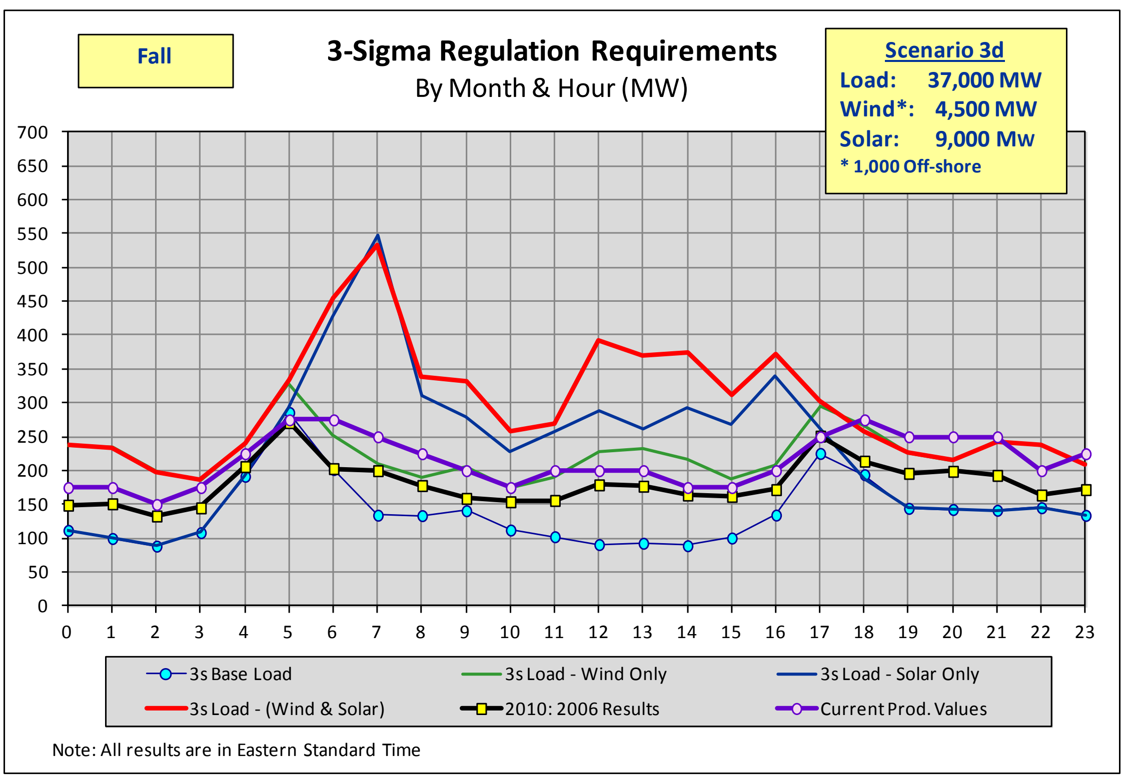


Figure 7-26: Scenario 3d Fall Regulation Results

## 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 dispatchability, 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 (DC) or of wind exceed 2,500 MW. There is also upward pressure on regulation requirements as the penetration levels increase to 9,000 MW (DC) of solar PV and to 4,500 MW of wind[9] 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.

[9] 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. Status of Other Power Systems

There are several power systems in the world that are experiencing high solar penetration levels and/or growth, notably Hawaii, Germany, California, and Massachusetts. Hawaii has unique challenges because it consists of several small island systems with very high solar penetration. It is not particularly comparable to New York. The other three systems are all part of interconnected grids and have moderate ties to neighboring systems. Further, all have higher concentrations of solar than does New York.

The German power grid has a system peak of approximately 80 GW and is centrally located within their interconnection grid (*i.e.*, mainland Europe). Their renewable energy generation base includes about 40 GW of wind power and 40 GW of solar PV. 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.

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[10] 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.

[10] 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:

- **No bulk power system reliability issues are anticipated for solar PV and wind penetrations level studied ( *i.e.*, up to 4,500 MW wind and 9,000 MW solar PV).[11].** 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 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. Additionally, while not evaluated in this study, minor increases in regulation requirements may be further mitigated through the implementation of potential storage technologies or other measures within the State.

- **The large-scale implementation of behind-the-meter solar PV will impact the NYISO's load profile and associated system operations.** It is therefore recommended that the NYISO 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 FERC 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 also recommended that the NYISO request that the NYPSC and the 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 has been shown in other regions to have 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

[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.

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 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 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 adds to the bulk power system's ability to move renewable resources to load centers within New York.