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ISO New England Net Load Analysis with High Penetration Distributed PV

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SUMMARY

Many Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) in the United States are witnessing the proliferation of solar photovoltaic (PV) resources interconnected at the distribution level within their respective balancing authority areas. Such rapid growth will eventually impact the effectiveness of the methods used by ISO/RTOs to plan and operate their system, and to a degree that is commensurate with existing and anticipated PV penetration. Understanding the nature, timing, and magnitude of these impacts is critical and often requires the development of simulations of future PV growth scenarios that capture the unique solar, load, resource, and infrastructure characteristics of each system. ISO New England (ISO-NE), the ISO/RTO for the New England region of the US, has witnessed significant growth of distributed PV resources over the past several years, and is evaluating and preparing for the impacts that future PV growth will have on system planning and system operations. As part of these efforts, a simulation of the effects of higher-than-forecasted amounts of distributed PV on the region's load profile was performed, and key results are discussed in this paper.

KEYWORDS

Distributed energy resources, distributed generation, solar photovoltaics, net load, capacity value, integration of large scale renewables

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1.0 INTRODUCTION

Between January 2010 and May 2015, the total installed nameplate capacity of distribution-connected PV resources in New England increased from 44 MW to more than 1,000 MW. (Note that all references to PV capacity herein reflect MW_{ac}). Figure 1 (left) illustrates the spatial distribution of PV capacity deployed in the region at the end of 2014. Within the next 10 years, ISO-NE forecasts that PV installations will total almost 2,500 MW [1]. However, future trends with respect to the interrelated factors influencing PV adoption (e.g., installed PV costs, wholesale/retail electricity rates, and federal, state, and local policies) could result in additional PV deployment.

While system operators cannot dispatch distributed PV and do not receive telemetered data concerning its real-time operation, these rapidly-growing resources eventually cause significant reductions in system load. Further, their load-reducing behaviour is governed (primarily) by the availability of solar irradiance, which exhibits spatial variability and temporal variability across all timescales. These characteristics pose new challenges to the core functions of system operations [2], including but not limited to: short-term load forecasting supporting the efficient commitment and dispatch of system resources [3]; allocation of sufficient regulation and operating reserves; expectations concerning the disturbance tolerance characteristics of systems with large amounts of distribution-connected generation [4-5]; and ensuring sufficient ramping/cycling capability exists among the resources used to serve the increasing volatility of net load [6].

In addition to working to mitigate the operational impacts described above, system planners need to reflect anticipated amounts of distributed PV in their long-term load forecasts and in their evaluation of the need for future system resources (e.g., generation, demand response, etc.) and transmission infrastructure. Integral to these considerations is an understanding of PV's impacts on future peak net loads and the related issue of its appropriate capacity valuation [7]. Further, very high PV penetration scenarios require a consideration of the frequency response and transient stability of future systems that may have a large share of synchronous generation displaced by asynchronous, inverter-based generation [8].

One method of identifying the impacts noted above is simulating and analysing net load profiles in high penetration PV scenarios, which can give a strong indication of key future system characteristics that will be important to system operators and planners. The analysis and results of a net load simulation for ISO New England with up to 8 GW of distributed PV are discussed below.

2.0 METHODOLOGY

The net load simulation discussed herein is based on coincident, historical hourly load and PV production data for the years 2012, 2013, and 2014. The use of coincident load and PV data ensures that the simulation reflects the effects of weather contemporaneously influencing both load and PV performance. Given that some of the PV installed in New England participates in ISO-NE's wholesale energy market, production from these resources was added back into the hourly loads in order to remove all load reductions due to solar, thus creating a baseline "No PV" load scenario. Solar data used for the analysis included energy production data corresponding to a total of 665 PV sites in the region (with locations shown in the right-hand plot in Figure 1). These PV installations total 82 MW in nameplate capacity, and their data was accessed via Solectria Renewables' SolrenView web-based monitoring system [9]. Using these data as a representative subset of all PV currently deployed in the region, normalized state-by-state PV profiles were developed and then blended into a regional normalized profile based on each state's share of the long-term regional PV forecast. PV scenarios of up to 8 GW in nameplate capacity were then developed in 1 GW increments via upscaling [10] of the normalized regional profile. Note that while the PV profiles described above reflect existing (and not necessarily future) PV system design and technology trends in New England, these trends are not anticipated to change significantly over the next decade. It is therefore assumed that the upscaling of these profiles yielded a reasonable estimate of future profiles associated with larger PV fleets.

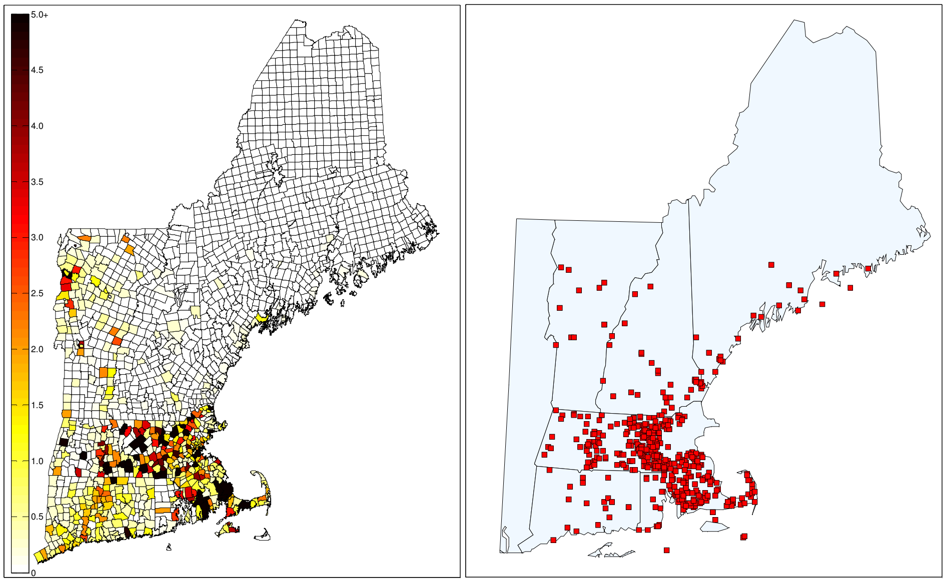

Figure 1: Left: Heat map of the town distribution of PV capacity (MW_{ac}) on December 31, 2014; Right: Locations of the 665 SolrenView PV sites

3.0 SEASONAL NET LOAD PROFILES

Discussed below are illustrative ISO-NE daily net load profiles representing typical summer, winter, and shoulder season loads, as well as trends in net load ramps, with up to 8 GW of PV.

3.1 Summer Net Load Profile

The all-time highest ISO-NE system peak of 28, 130 MW occurred on August 2, 2006. Below is a plot of net load profiles associated each PV scenario on July 19, 2013, the peak load day of the load dataset and the all-time fourth highest ISO-NE peak load day. Shown is distributed PV's effect on the timing of the peak net load (blue dots), which becomes later in the afternoon as PV penetrations grow. This results in PV's incremental contribution to serving summer peak net loads diminishing as PV penetrations grow due to the setting of the sun. At intermediate PV penetrations, this may not be as relevant for PV systems employing tracking devices, which are capable of significant power production later in the afternoon; however, at very high penetrations the timing of peak net loads will eventually approach dusk, when PV will no longer serve peak load without incorporating energy storage.

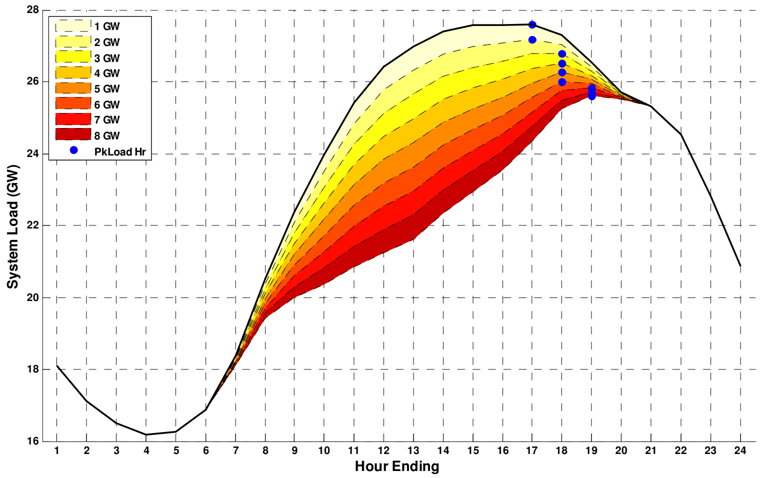

Figure 2. Net load profiles for July 19, 2013

Figure 3 is a series of six scatter plots illustrating the timing and magnitude of the daily peak net loads during the summer season (June, July, and August) for six PV scenarios: no PV and 1, 2, 4, 6 and 8 GW of PV. The plots show that without PV summer peak loads occur in hours ending (HE) 14-18, but beginning with the 6 GW PV scenario, the timing of peak net loads shifts to HE 19-20. Overall, peak net load reductions of approximately 2 GW were observed in the 8 GW PV scenario.

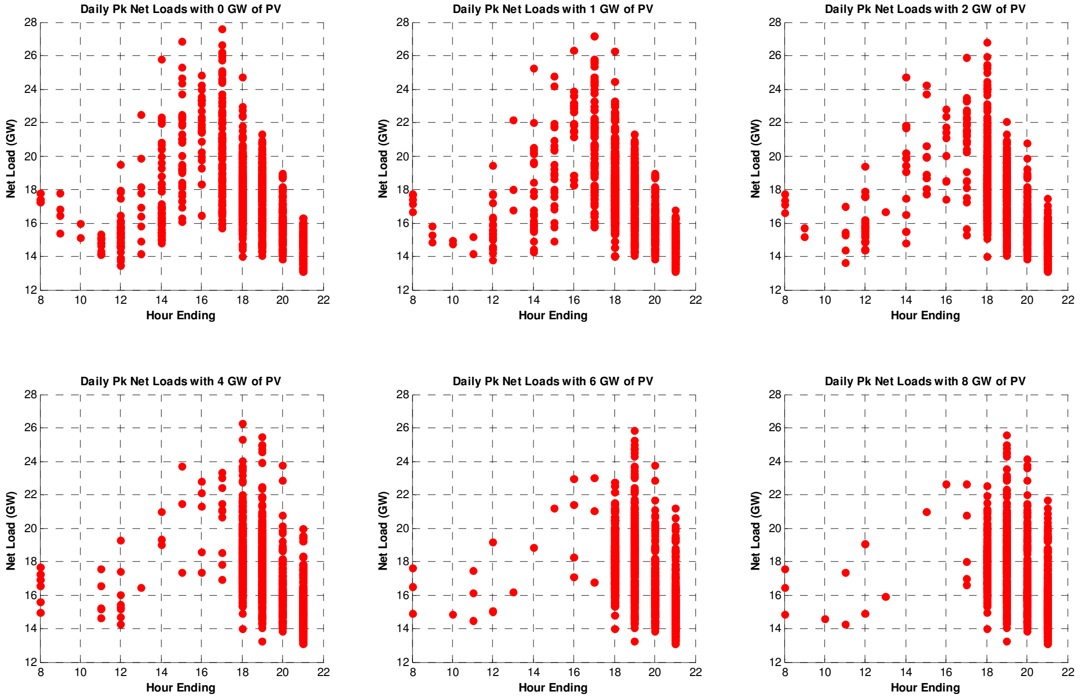

Figure 3. Scatter plots of the timing and magnitudes of summer daily peak net loads with 0, 1, 2, 4, 6, and 8 GW of PV, respectively in a clockwise direction.

3.2 Winter Net Load Profile

The all-time highest ISO-NE system winter peak of 22,818 MW occurred on January 15, 2004. Figure 4 illustrates winter net load profiles for January 7, 2014. Clearly shown are the load reductions from PV during the middle of the day, resulting in an increased need for midday ramping capability from non-PV resources – first in the down ramping during the late morning, and then subsequently during the afternoon up ramp. Also shown is how PV will not reduce the winter peak load due to its late afternoon/early evening timing.

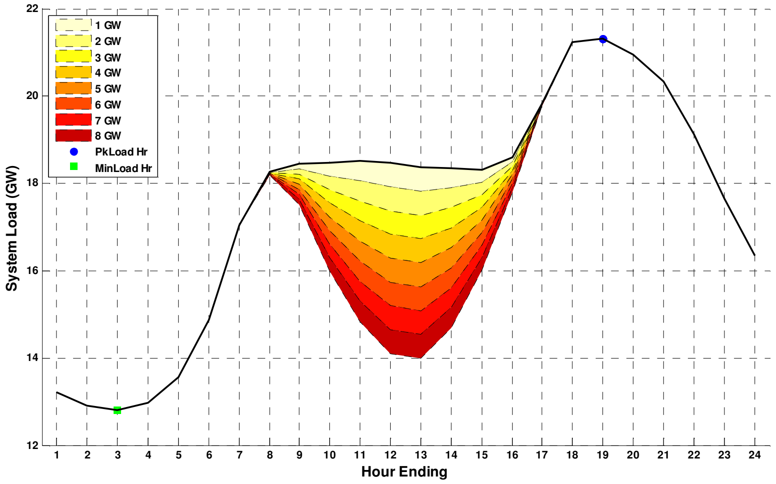

Figure 4. Net load profiles for January 7, 2014

3.3 Shoulder Season Net Load Profile

The lowest system loads in New England most often occur on weekend days during spring and autumn months when temperatures tend to be milder and there is low demand for heating/cooling. Collectively, these months are often referred to as the "shoulder season". Figure 5 is a plot of net load profiles for Sunday April 20, 2014, the day with the lowest simulated net loads, and illustrates the dramatic extent of load masking that typifies midday hours of light load days with high PV penetration. This plot also clearly demonstrates the accompanying potential for significant displacement of synchronous generation by PV (and other inverter-based generation such as wind or fuel cells), and emphasizes the need to mitigate reliability issues that may result (e.g., voltage regulation, frequency response, and transient stability). Further illustrated is the manner in which minimum loads will decrease and the hour in which they occur, identified with green squares, will shift from overnight (HE4) to midday hours (HE14-15). These hours are important because they indicate the timing of potential minimum generation emergency events. These are abnormal events when generation and external transactions exceed system demand, and can result in excessively high system voltages and unscheduled power flows into neighbouring regions.

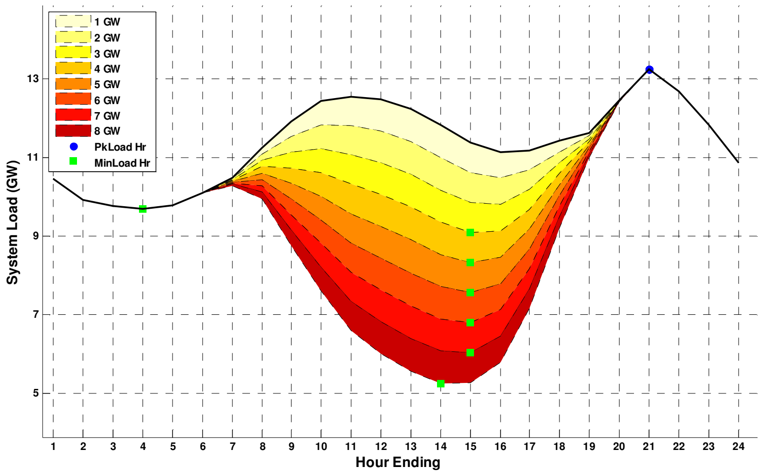

Figure 5. Net load profiles for April 20, 2014

4.0 HOURLY NET LOAD RAMP RATES

Net load ramping characteristics often help identify the future ramping capabilities needed from the balance of resources given higher PV penetrations. The maximum hourly up ramps and down ramps of the three year load dataset (without PV) are tabulated below. Given PV's seasonal/diurnal characteristics, increased penetrations will not significantly change the maximum ramps; however, greater variability in net loads should be expected.

Maximum Up Ramps	Date	Maximum Down Ramps	Date
3,140 MW	Sun, 1/29/12 (HE18)	-2,220 MW	Wed, 9/11/13 (HE23)
2,320 MW	Tue, 1/22/13 (HE7)	-2,190 MW	Mon, 7/15/13 (HE23)
2,280 MW	Mon, 3/24/14 (HE7)	-2,190 MW	Mon, 7/15/13 (HE24)
2,240 MW	Mon, 10/28/13 (HE7)	-2,180 MW	Tue, 7/16/13 (HE23)
2,230 MW	Tue, 12/17/13 (HE7)	-2,180 MW	Tue, 7/16/13 (HE24)

Figures 6-8 are boxplots showing the distribution of hourly load ramps without PV (red boxes), with 4 GW PV (green boxes), and with 8 GW PV (blue boxes), and during winter (December/January), summer (July/August), and shoulder season (April/May), respectively. Figures 6 and 7 reflect non-holiday weekdays only, whereas Figure 8 reflects only weekend days in order to identify the ramping trends during the times of year with the lowest loads (e.g., those shown in Figure 5). The particular hours illustrated (e.g., 'HE8') are identified along the top of each set of boxplots. Winter observations include increased down ramping in the morning and increased up ramping in the afternoon. The summer plot highlights a tendency for decreased up ramps in HE 7-8, increased up ramps in HE13-19, and overall increased magnitudes of down ramps in HE 6-13 for the 4 GW and 8 GW scenarios. The shoulder season weekend plot shows significant increases in morning down ramps and afternoon up ramps, with many up ramps exceeding 2,000 MW during HE 17-19 in the 8 GW scenario. In general, all three figures illustrate that large amounts of distributed PV cause increased net load ramping and a higher frequency of larger magnitude ramps, especially on days exhibiting both high irradiance and low load.

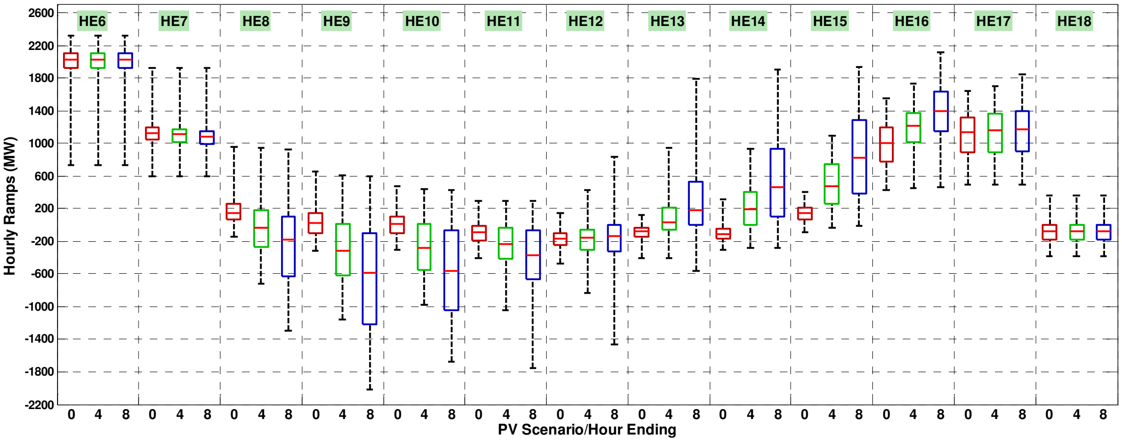

Figure 6. Hourly net load ramps during December/January (non-holiday weekdays only)

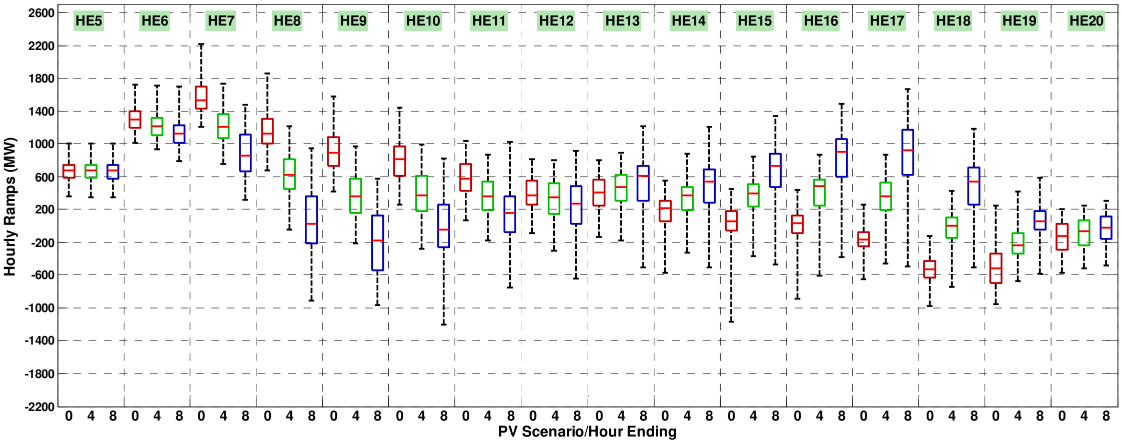

Figure 7. Hourly net load ramps during July/August (non-holiday weekdays only)

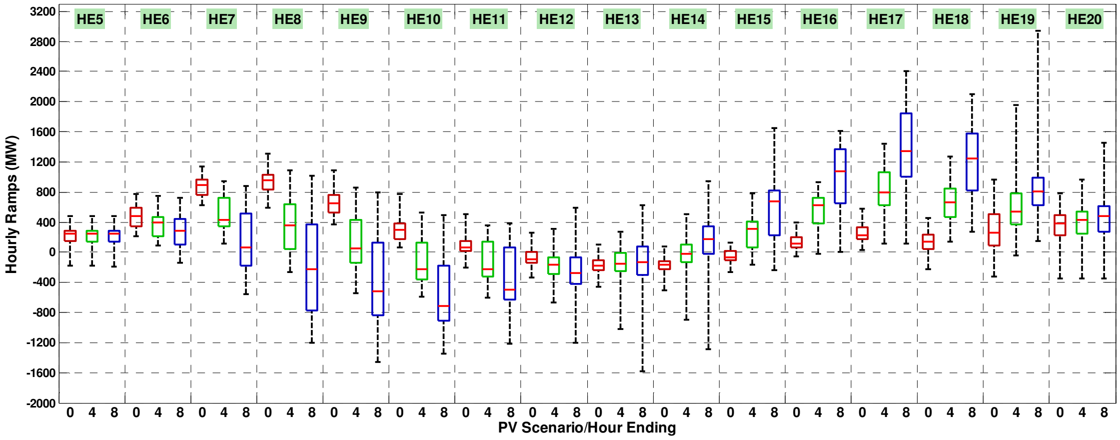

Figure 8. Hourly net load ramps during April/May (non-holiday weekends only)

5.0 CONCLUSIONS

The simulation and analysis of net load characteristics under high PV penetration scenarios is a method of identifying key challenges associated with increased penetrations of distributed PV. ISO-NE net load characteristics, including seasonal profiles, the timing of summer peak load, and trends in seasonal net load ramping, were evaluated for distributed PV scenarios up to 8 GW. Results highlight significant changes to the overall system and some of the accompanying challenges that would need to be addressed in order to efficiently and reliably integrate the amounts of PV evaluated, including:

1. Understanding the effect on the timing and magnitude of summer peak loads;
2. Ensuring there is sufficient ramping/cycling capability among non-PV resources to serve the increasingly volatile net loads;
3. The need to mitigate potential reliability issues associated with significant displacement of synchronous generation and increased potential for minimum generation events.

Lastly, similar analyses performed on sub-hourly data (e.g., 5-minute or 1-minute) would likely yield additional insights, such as potential impacts on regulation requirements.

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