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The challenge of integrating offshore wind power in the U.S. electric grid. Part II: Simulation of electricity market operations

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ABSTRACT

The purpose of this two-part study is to analyze large penetrations of offshore wind power into a large electric grid, using the case of the grid operated by PJM Interconnection in the northeastern U.S. Part I of the study introduces the wind forecast error model and Part II, this paper, describes Smart-ISO, a simulator of PJM's planning process for generator scheduling, including day-ahead and intermediate-term commitments to energy generators and real-time economic dispatch. Results show that, except in summer, an unconstrained transmission grid can meet the load at five build-out levels spanning 7–70 GW of capacity, with the addition of at most 1–8 GW of reserves.

In the summer, the combination of high load and variable winds is challenging. The simulated grid can handle up through build-out level 3 (36 GW of offshore wind capacity), with 8 GW of reserves and without any generation shortage. For comparison, when Smart-ISO is run with perfect forecasts, all five build-out levels, up to 70 GW of wind, can be integrated in all seasons with at most 3 GW of reserves. This reinforces the importance of accurate wind forecasts. At build-out level 3, energy from wind would satisfy between 11 and 20% of the demand for electricity and settlement prices could be reduced by up to 24%, though in the summer peak they could actually increase by up to 6%. CO_2 emissions are reduced by 19–40%, SO_2 emissions by 21–43%, and NO_x emissions by 13–37%.

This study finds that integrating up to 36 GW of offshore wind is feasible in the PJM grid with today's generation fleet and planning policies, with the addition of 8 GW of reserves. Above that, PJM would require additional investments in fast-ramping gas turbines, storage for smoothing fast-ramping events, and/or other strategies such as demand response.

1. Introduction

PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity serving 13 states and the District of Columbia, covering from the mid-Atlantic region out to Chicago [10,11]. Acting as a neutral, independent party, PJM operates a competitive wholesale electricity market and manages the high-voltage electricity transmission grid to ensure reliability for more than 61 million people. Fig. 1 shows the geographical area covered by PJM and the high-voltage backbone (345 kV and higher) of its transmission grid.

At the end of 2013, the total installed capacity within the PJM market was about 183 Gigawatts (GW) and the peak load during the year was over 157 GW [8]. The yearly generation in PJM by percentage of each fuel source between 2010 and 2013 is shown in Table 1 [5–8].

The basic functions of PJM comprise grid operations (supply/demand balance and transmission monitoring), market operations (managing open markets for energy, capacity and ancillary services) and regional planning (15-year look-ahead) [10,11]. The interest in this paper is to analyze the ability of the energy market and the transmission grid within the PJM area to integrate non-dispatchable generation in quantities much larger than the current levels. As indicated in Table 1, in 2013 wind power corresponded to less than 2% of the total generation. The Mid-Atlantic offshore wind power production proposed and modeled in Part I of this two-part paper [2] would bring that fraction to as much as 28% at certain times of the year, thus raising the question of how to manage the generation schedule and the transmission grid capacity under such a scenario.

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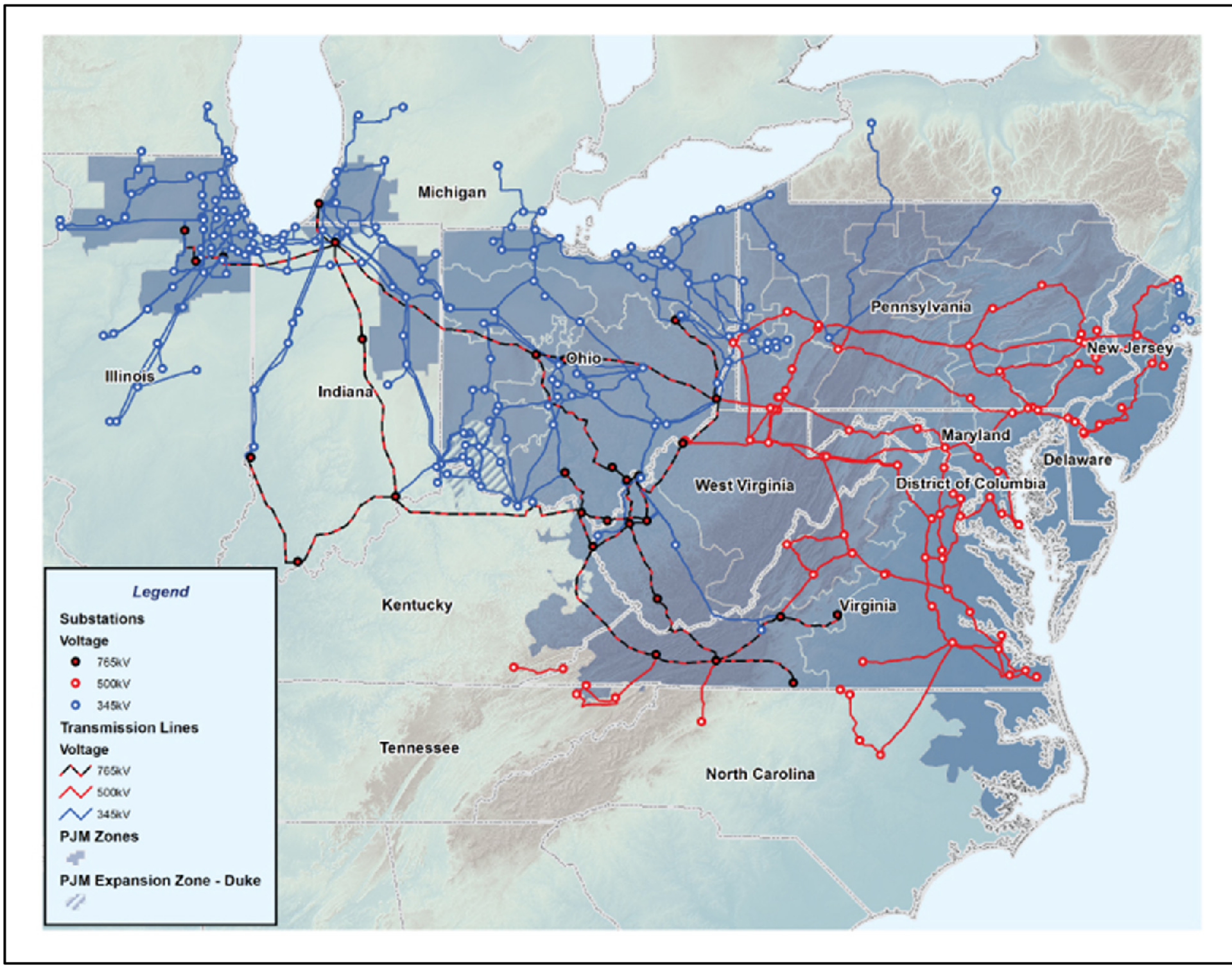

Fig. 1. PJM high-voltage backbone.

Table 1
PJM actual generation by fuel source (%) between 2010 and 2013.

Fuel source	2010	2011	2012	2013
Coal	49.3	47.1	42.1	44.3
Nuclear	34.6	34.5	34.6	34.8
Gas	11.7	14.0	18.8	16.3
Hydroelectric	2.0	1.9	1.6	1.8
Wind	1.2	1.4	1.6	1.9
Other	1.2	1.1	1.3	0.9

In order to answer this question, this paper introduces SMART-ISO, a simulator of the market operations of PJM, including the transmission grid. Developed at PENSA Lab at Princeton University, SMART-ISO is a detailed model of the PJM planning process designed specifically to model the variability and uncertainty from high penetrations of renewables. It captures the timing of information and decisions, stepping forward in 5-min increments to capture the effect of ramping constraints during rapid changes in wind energy.

The higher levels of wind power penetration in the PJM market analyzed in this study are not likely to become reality for at least another two decades. This paper tries to answer questions about how to manage the system in those future scenarios by using the current structure of the market, namely, the current power supply sources, transmission grid and operating policies. Though it is expected that the market structure may change significantly in that time frame (e.g., less coal-based generation, more distributed generation, relief in transmission constraints, and improved forecasting performance), anticipating these changes is beyond the scope of this paper. The results obtained in this study are useful in that they reveal some of the limiting factors in the current market and point to the direction to follow in order to overcome these limitations.

2. The SMART-ISO model

SMART-ISO is a simulator of the market operations of PJM that aims to strike a balance between detailed representation of the system and computational performance. It comprises three optimization models embedded within a simulation model that captures the nested decision-making process:

1. Day-ahead unit commitment (DA-UC) model.
2. Intermediate-term unit commitment (IT-UC) model.
3. Real-time economic dispatch.

Accurate modeling of the nesting of these three models is a central (and powerful) tool used by RTOs to adapt to uncertainty. In SMART-ISO all three optimization models include a DC approximation of the power flow. In addition, an AC power flow model is run after both the intermediate-term UC and the real-time economic dispatch models in order to verify the electrical stability of the grid.