Energy Policy 95 (2016) 196–210

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Implications of environmental regulation and coal plant retirements in systems with large scale penetration of wind power

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HIGHLIGHTS

- Retirement of coal plants may increase transmission congestion and LMP prices.
- EPA rules might lead to significant reductions in emission of air pollutants.
- Wind geographical diversity may reduce transmission constraints and air emissions.
- At times of high peak load, wind may not reduce system stress caused by retirement.
- RPS policies can support and mitigate negative impacts of EPA regulations.

ARTICLE INFO

Article history:
Received 23 May 2015
Received in revised form
2 March 2016
Accepted 8 April 2016

Keywords:
Coal power plant retirements
Security constrained unit commitment
Power system reliability
Wind integration
EPA's regulations
Renewable Portfolio Standards

ABSTRACT

Over the last decade there have been a growing number of federal and state regulations aimed at controlling air emissions at power plants and/or increasing the penetration of renewable resources in the grid. Environmental Protection Agency regulations will likely lead to the retrofit, retirement, or replacement of coal-fired power plants while the state Renewable Portfolio Standards will continue to drive large-scale deployment of renewable energy sources, primarily wind. Combined, these changes in the generation fleet could have profound implications for the operations of the power system. In this paper, we aim to better understand the interaction between coal plant retirements and increased levels of wind power. We extensively analyze the operations of the PJM electricity system under a broad set of scenarios that include varying levels of wind penetration and coal plant retirements. Not surprisingly, we find that without transmission upgrades, retirement of coal-fired power plants will likely result in considerable transmission congestion and higher energy prices. Increased wind penetration, with high geographic diversity, could mitigate some of the negative effects of coal plant retirement and lead to a significant reduction in air emissions, but wind forecast error might impose operational constraints on the system at times of peak load.

1. Introduction

The U.S. Environmental Protection Agency (EPA) has a number of existing and upcoming environmental regulations that will likely result in the significant retrofit, early retirements, or replacement of coal-fired power plants (Fleischman et al., 2013; IER, 2015; U.S. Energy Information Administration, 2014). Early retirements may take place when generator owners cannot afford the additional investment in the pollution control devices needed to fulfill environmental regulations. Expectations about regulations to limit emissions of criteria air pollutants (like the Cross State Air Pollution Rule (CSAPR) and Mercury and Air Toxic Standards (MATS)) may be driving some plant retirement decisions. While in June 2015 the U.S. Supreme Court remanded MATS (which was finalized in 2011 and with a compliance deadline of April 2015) to the D.C. Circuit Court to decide whether or not to invalidate the rule (MICHIGAN v. EPA, 2015), expectations about this rule are the major drivers of retirements. The MATS imposes the Maximum Achievable Control Technology (MACT) to new or modified generators with emissions of mercury, arsenic, acid gas, nickel, selenium, and cyanide. The standard defines an emission level, known as MACT floor, based on the best performing technology currently available for a source. Hence, any new or modified generators must adopt an emission control technology that limits the emission to the level equivalent or lower than the MACT floor (ERA

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http://dx.doi.org/10.1016/j.enpol.2016.04.015
0301-4215/© 2016 Published by Elsevier Ltd.

Environmental, 2014). Similarly, emerging regulations on hazardous air pollutants, combustion residuals, and cooling water (Aydin et al., 2013), as well as the final Clean Power Plant rule for existing power plants (EPA, 2015) are cause for concern for coal power plant owners. Finally, while not a result of regulatory action, low natural gas prices observed over the last couple of years have also driven down electricity prices and have thus discouraged retrofitting efforts at coal plants (U.S. Energy Information Administration, 2014). The Energy Information Administration (EIA) estimates that as a result of federal regulations, 50 GW of the 310 GW of the total existing coal-fired generation capacity in the U.S. (or 16%) may be retired by 2020 (U.S. Energy Information Administration, 2014).

Regulatory efforts at the state level are also driving changes to the power generation fleet. 29 states currently have Renewable Portfolio Standards (RPSs) mandating that a certain percentage of electricity sold in a state be produced with renewable energy (NC State University, 2014). Wind power has been the leading renewable resource in the U.S. and while there was a decrease in the growth rate of wind installations in 2013, U.S. wind aggregated capacity grew from 2539 MW in 2000 to 67,870 MW in July 2015 (AWEA, 2015; U.S. Department of Energy, 2015). Furthermore, the RPSs and the availability of cost-effective wind technology will likely continue to drive growth in wind installation in 2016 and beyond (Wiser and Bolinger, 2014). Since wind power is a variable and intermittent electricity source, it requires that conventional generators be available to provide balancing services. Coal and natural gas power plants have traditionally been considered to be the most suitable thermal resources to balance the low frequency variability of wind (Fertig et al., 2012). Coal retirements may thus affect the grid's ability to efficiently integrate larger levels of wind power generation.

There are a number of studies evaluating the effects of coal power plant retirements on energy prices. For example, Aydin et al. (2013) broadly investigated the feedback effects of power plant retirements on the short and long-term wholesale energy prices, while Pratson et al. (2013) studied how natural gas prices and environmental regulations shift power generation from coal to natural gas power plants. Considering production cost for 304 coal and 358 natural gas power plants, Pratson et al. (2013) concluded that low natural gas prices would challenge 9% of coal capacity, while stringent environmental regulations would challenge another 56% of coal capacity.

Significant work is also available regarding the challenges and opportunities for integrating wind power into the grid (Enernex Corporation, 2010; GE Energy, 2010; Heeter et al., 2014; Katzenstein et al., 2010; Mauch et al., 2013a; Oates and Jaramillo, 2013; Shafiullah et al., 2013). For the PJM system in particular, the National Electric Reliability Corporation (NERC, 2014) studied the reliability implications of Renewable Portfolio Standards. The authors estimated that 38 GW of renewable capacity would be required to meet the 2028 RPS target in states where PJM operates. The authors also concluded that there will be a need for large transmission investments in order to achieve this RPS target.

To date, however, no analytical studies have been conducted to explicitly evaluate the interactions between various decisions related to the retirement, retrofit, or replacement of coal plants and increasing levels of wind, and the effects of these interactions on the operation of the power system. In this work, we modeled the PJM system to evaluate these interactions. The PJM system relies heavily on coal power and will likely face significant plant retirements (Aydin et al., 2013). Further, most of the states that PJM serves, with the exception of Kentucky and Tennessee, have RPS. For this analysis, we developed a broad set of scenarios that capture plausible characteristics of a future generation mix. We based these scenarios on data from Energy Exemplar's Eastern Interconnection (EE-EI) database, the EPA's Power Sector Modeling Platform v.5.13 (EPA, 2013), and the Eastern Wind Dataset (EWD) (NREL, 2012). Since the goal of this study is to identify the interaction between coal power plants and a high level penetration of wind, we did not consider transmission system upgrades beyond what was completed in 2013. Considering transmission system upgrades is beyond the scope of this paper and would render an obscure understanding of the combined effects of coal plant retirements and high wind penetration.

2. Method

2.1. Simulation approach

2.1.1. Security constrained unit commitment model

In this work, we used a full chronology security constrained unit commitment (SCUC) model to evaluate steady state operations of the PJM system. We solve the SCUC model for a horizon of one year with hourly resolution and daily steps. The objective in the SCUC model is to find a least cost generation dispatch considering a variety of constraints on generation and the transmission systems. We used the PLEXOS software to run the SCUC model (Energy Exemplar, 2014a; Nehrir et al., 2011). PLEXOS provides three solution techniques for solving a SCUC problem: mixed integer programming (MIP), linear relaxation (LR), and rounded relaxation (RR) techniques. In the MIP, PLEXOS uses classical exact optimization approaches to find the optimum solution while in LR, it relaxes integrality of binary variables and then solves the problem using linear programming techniques. In RR, PLEXOS still uses the linear programming techniques, but it generates an integer solution through iterative algorithms (heuristics). Only the RR and MIP capture units' minimum up and down times, and minimum stable levels (Higgins and Foley, 2013). In this paper, we use the MIP solution technique, solved with the CPLEX optimizer, to model the SCUC problem, resulting in more accurate solutions compared to the LR and RR techniques.

2.1.1.1. Objective function. The objective function includes production cost (calculated as a product of average heat rate, fuel costs, and output generation), and hot and cold startup costs.

2.1.1.2. Transmission line/interface modeling. We modeled the transmission system using maximum and minimum thermal limits for lines and transformers. In addition, we modeled the power flow constraints using Power Transfer Distribution Factors (PTDF) (Wood et al., 2013). PTDFs are coefficients that are calculated by the admittance matrix and define how much the variation of the power in system buses influences the flow of a transmission line. In order to reduce the size of the transmission system model, we ignored distant power sources/loads that have only negligible effect on the flow of certain transmission lines. We implemented this system size reduction by applying a 0.05 cutoff on the PTDF coefficients (Karll et al., 2012). We also modeled transmission interfaces, also called flowgates, which are groups of transmission lines for which their aggregated flow are maintained below a certain value to ensure system reliability. Flows of an interface are calculated by superposition of its individual transmission lines (Karll et al., 2012).

2.1.1.3. Reserve requirements. We address *N-1* Security constraints by including spinning and non-spinning reserve requirements in the model. *N-1* security constraints ensure that the system would continue its reliable operation even after failure of a component such as a transmission line or a generator. These reserves are meant to cover the load for a short period of time, usually 10 min,