The Electricity Journal 29 (2016) 55–63

Contents lists available at ScienceDirect

The Electricity Journal

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

Energy Policy Institute's Sixth Annual Energy Policy Research Conference

Carbon-based bidding structure in competitive electricity markets

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ARTICLE INFO

Article history:
Available online 2 November 2016

Keywords:
Electricity markets
Linear programming
Carbon emissions
Dispatch optimization

ABSTRACT

With changes to carbon output imminent as a result of governmental policies, the method by which energy generators in competitive markets are selected for operation can be called into question. We first simulated a bid-based day-ahead market with human participants and then analyzed generation asset owners' profits based on bid strategy. We then studied computing generator unit dispatch for this simulated market by introducing an environmental index related to the carbon intensity of the relevant fuel type, and computing dispatch via linear programming to either maximize or minimize this index subject to the constraint that average profits be the same as in the original market simulation. The results show that lower bids, even below cost, are most profitable for generators, and that adding an environmental weighting to the bid process has the potential to reduce carbon intensity of power generation without reducing overall average profitability to generators or increasing cost to consumers. This research concludes an environmental score should be explored as a potential weighting factor in bid-based electricity market dispatch.

1. Introduction

As the United States population grows, so does electricity demand and stress on existing electricity institutions and infrastructure. Increased demand, together with international commitments to reduce carbon emissions, are expected to lead to the increasing inclusion of novel and low-carbon energy-production technologies (Restuccia, 2015). Restructured electricity markets in the United States and abroad must meet changing demand and regulatory constraints while maintaining low-cost reliable power and a business environment that allows generators to operate profitably. This research analyzes a day-ahead bid-based dispatch market, and the implications of adding environmental weighting to dispatch optimization decisions.

2. Background—Electricity markets, PJM, and market simulation

One of these independent energy markets is the Pennsylvania, Jersey, and Massachusetts (PJM) energy market, which is used as a basis for the simulated system in this research. Responsible for managing over 67,000 MW of generating capacity, PJM is the world's largest competitive wholesale energy market (Ott, 2003). PJM began in 1927 as the first pooled resource generation system (PJM, n.d.), which allowed for three generation systems to be interconnected improving overall system reliability. This was a controlled system where PJM projected demand and dispatched capacity as needed. In 1997, this controlled system was changed as PJM became the first independent system operator (ISO). This independence allowed PJM to open the first bid market system in the United States (PJM, n.d.). This new bid system allowed anyone who generated electricity to place a bid to PJM, these bids were ranked lowest to highest by cost with the lowest bid units being selected by PJM first until the selectety -30ptd unit capacity met the projected demand, subject to transmission and reliability constraints. The market clearing price, the price which all units are paid, is selected by the bid price of the final unit selected to meet the necessary capacity (Ott, 2003). Soon after ISO's began operation, the Federal Energy Regulation Commission (FERC) began pushing these ISO's to consolidate into Regional Transmission Organizations (RTO) which are able to better process a larger number of generation and transmission transactions. In 2002, PJM became the United States' first RTO and has operated the expanding market of the Northeast United States ever since (PJM, n.d.).

PJM is currently composed of two energy markets, the real-time balancing market, and the day-ahead market (PJM, n.d.). The real-

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http://dx.doi.org/10.1016/j.tej.2016.09.010

Nomenclature

Notation and Abbreviations
c Capacity (MWh/h)
φ Dispatch variable, fraction of available generation capacity that is dispatched
f Forced out rate, probability that a particular generating unit will not be able to run
ω Wind (MWh/h)
ρ Profit ($)
ψ Fuel cost ($)
b Bid price ($/MWh)
s Total environmental index
t Time (hours)
e Environmental index score for each fuel type
h Heat rate (Btu/kWh)
m Cost of operations and maintenance for electricity generating units ($/MWh)
κ Market clearing price ($/MWh)
u Generating unit
p Time period (peak, shoulder, off-peak)

time balancing market actively manages the capacity, demand, and clearing price for the market every five minutes. This market allows for units priced out of the day-ahead market to find chances to remain active (Ott, 2003). The day-ahead market is calculated for each hour of the next day, and is based on generation offers, demand bids, virtual supply offers, virtual demand bids and bilateral transaction schedules which come from generators and are given to the PJM market operator. PJM then selects the units based on price and demand, producing a market clearing price which is a binding price for that time period. These binding prices allow for electricity producers to then sort out their transmission transactions based on transmission limitations and demand, producing a locational marginal price (LMP) for each location in the system (Ott, 2003).

While this bid-based system currently operates effectively to provide reliable power at reasonable prices to consumers, it is not known whether or not this is the most efficient system to reduce carbon outputs, or increase profits for generators (Ott, 2003). To analyze a bid-based system, a simplified version of a day-ahead energy market (based loosely on PJM day-ahead markets) was simulated in this research, as described in Section 4. The simulation included 762 generation units owned by nine generation companies. Proportional demand to capacity ratios were generated using information provided by PJM (PJM, n.d.). Fuel costs and wind energy generation varied from round to round, with each round simulating a single day of operation. Each round was broken into three time periods (peak, shoulder, and off-peak) as opposed to the hourly system used for the day-ahead market of PJM. Generation units included coal, natural gas, and nuclear plants, each with forced outage rates and operations and maintenance costs based on approximate industry-standard information (Ott, 2003; PJM, n.d.). These simplifications in assumptions and input parameters allow simplification of the calculations used to get meaningful results.

3. Problem statement and hypothesis

Since FERC Order 888 was issued in 1996, transmission providers have been required to provide equal access to the transmission grid to non-utility generators, effectively opening many electricity control areas to wholesale competition among traditional and independent power producers (Federal Energy Regulatory Commission, 2010). However, this process does not equate the "cleanest" method of energy production as that does not have priority to the decision making authority (Walden et al., 2015; Project Management Institute, 2008).

The competitive nature of the bidding process means that short-term profitability is not assured for any generation asset that is participating in a market. We hypothesize that average unit profitability could be maintained and carbon emissions substantially reduced if, instead, a fixed profit margin were allowed to each unit, and units were dispatched on an emissions-based rather than a cost-based score.

4. Methodology

In this work we compare the results of the optimization of dispatch of electricity generating assets using two approaches and models. The first uses a bid-based dispatch simulation, and relies on human actors to create profit-maximizing bid strategies. The second uses an optimization strategy with profitability as a constraint, rather than an objective function, and with minimizing an environmental index (a proxy for carbon emissions) as its objective. The following sections describe the methodology used in each of these optimization strategies

4.1. Profit Maximization—Human bids

To analyze the market participant behavior and resultant electric generation unit dispatch in a competitive market, we used a model simulating a day-ahead bid-based market, similar to that created by PJM, with simplifications to eliminate transmission and security constraints, and using three time steps per day rather than the more realistic 24 hourly time steps used in PJM and most day-ahead markets.

Table 1
Example of Market Plan for a single bidding cycle.

	Forecast			Real			
Round 1		$/MMBTU	Wind				Wind
fuel:	natural gas	$4		fuel	natural gas	$4	
	coal	$2.50			coal	$2.45	
	nuclear	$1.25			nuclear	$1.28	
demand:		MWh/h					
	peak	24000	no	demand	peak	26600	67
	shoulder	16000	no		shoulder	15600	134
	off-peak	8000	no		off-peak	8600	200 f