21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2014 Grid of the Future Symposium

Impact of Lumpiness in Energy Supply Curves on Day-Ahead Energy Prices

V. DAWAR, M. MARWALI
New York Independent System Operator
USA

SUMMARY

Restructuring of the U.S. electricity industry in the 1990s changed the traditionally vertically integrated electric utility system. With restructuring, the generation and transmission, assets of electric utilities were "unbundled" as competition was introduced in wholesale electricity markets. Utilities were also required to provide open, non-discriminatory access to the transmission services they continued to own. Independent system operators were established to assure access to transmission and administer the wholesale electricity markets created in many regions of the nation. These electricity markets conduct auctions to determine wholesale electricity prices in day-ahead and real time. Many financial energy transactions are pursued in a day-ahead energy market with the real time energy market acting as a balancing market.

In this paper we will focus on the day-ahead energy market and day ahead energy prices. Various financial instruments drive day-ahead energy prices, including price sensitive bids by generating units, physical load demand and price sensitive bids by virtual transactions. Day-ahead energy price spikes can be defined as sudden increases in an energy price for relatively short time period. Literature has shown that energy price spikes can either be due to supply demand interactions or due to strategic withholding [1]. Supply / demand interactions can be categorized as a shortage in supply or substantial increase in demand whereas strategic withholding can be categorized as market power by generating units. Energy price spikes due to supply/demand interactions send the right price signals to market participants, whereas energy price spike due to strategic withholding should be carefully mitigated.

Energy price spikes may also be due to virtual transactions in wholesale energy markets. There is limited literature on energy prices spikes related to virtual supply and load bids. In this paper, we study the impact of virtual transactions on energy prices and study how lumpiness in supply curves can escalate this impact. We present a small case study to show how virtual load bids can result in day-ahead energy price spikes. Further, we also show that the frequency of day-ahead energy price spikes can increase if the generator bids and price sensitive virtual load bids are "lumpy".

KEYWORDS

Energy markets, Virtual bids, Optimization, Energy prices, Market power

vdawar@nyiso.com

BACKGROUND

Historically, electricity markets of the United States were vertically integrated. In a vertically integrated environment, a utility would own the generation, transmission and distribution assets of the electric system in their service territory. In the 1990s, the electric power industry was restructured and independent system operators (ISO) were established. An ISO runs a wholesale electricity market to allow trading between generators, retailers and other financial institutions. Other than providing a platform to buy and sell energy, an ISO helps to operate the grid reliably and optimally. An ISO runs electricity markets day-ahead and in real time and calculates day-ahead locational based energy prices (LBMPs) and real time LBMPs. In a perfectly competitive electricity market, each generator bids its marginal cost and there exists no market power. In reality, each ISO adopts certain measures to mitigate market power and increase market efficiency. One such mechanism to increase market efficiency is virtual bidding. Virtual bidding involves financial transactions scheduled in the day-ahead energy market and settled in the balancing market. ISOs allow the use of virtual transactions as they tend to converge day-ahead LBMP's and real time LBMP's, thereby promoting market efficiency and reducing customer cost.

The majority of market activity and settlements happens in the day-ahead energy market. The real time energy market is a balancing market based on the deviations of actual operations of generating units from their day-ahead energy schedule. In 2012 net day-ahead energy settlements in the New England electricity market were worth \$4.9 billion and net real time energy settlements were worth \$0.3 Billion [1]. Hence, the majority of settlements in the wholesale energy market depend on day-ahead LBMP's. Any price spike in day-ahead LBMP's should thereby be reflective of either scarcity in supply or high demand. Strategic withholding or any other market power should not be the cause of these price spikes.

In this paper, we investigate the impact of virtual transactions on day-ahead LBMP's. More importantly, we show how virtual transactions can introduce a price spike and hence send an inappropriate market signal. We also investigate the issues related to lumpiness in the supply curves. In section 2, we review the related literature on energy price spikes and describe the role of virtual transactions in the energy market. In section 3, we present a small example of five generators and three virtual load bids to show how virtual transactions can expose lumpiness in the energy market price. In section 4, we conclude the paper with potential measures that might help to mitigate the inappropriate price spikes that may be set by virtual transactions.

LITERATURE REVIEW

Various studies have been conducted on the issue of price spikes in the day-ahead wholesale electricity market. In a paper by John Kwoka [2] the study examines price spikes using two different analytical approaches. In a micro theoretic approach the study examines price spikes that are either supply or demand induced. A higher demand period during hot summer days can result in a demand induced price spike while a loss of a substantial generating capacity can result in a supply induced price spike. In an auction, generators can manipulate their bids resulting in energy price spike.

An example of demand induced price spike is seen in Texas market, where warm temperatures drove the hourly day-ahead electricity price to above \$500 per megawatt hour (MWh) between 5:00 pm and 6:00 pm on April 26 and April 27 2012 [3]. An example of supply induced price spike is seen in the Midwest ISO during the week of June 22-June 26 1998, where unplanned outage of an above average amount of generating capacity drove the price to extraordinarily heights for a narrow and short lived time interval, according to a report by FERC [4].

In this paper we study day-ahead energy price spikes due to virtual transactions. Energy price spikes indicate the degree of flexibility of supply and demand in responding to sudden changes in the system. In theory, energy price spikes, if sustained for larger time periods, should trigger new capacity additions. However, if energy price spikes are induced due to virtual transactions, they may not directly imply the need to add either new generation capacity or ramp flexibility. A virtual supply or load bid is a non physical financial transaction introduced in a day-ahead energy market only. A virtual load bid is a bid submitted by a market participant representing its willingness to buy a quantity (MW) at a cost ($/MWh) if the day-ahead LBMP goes below the bid. A virtual supply bid is a bid submitted by a market participant representing its willingness to sell a quantity (MW) at a cost ($/MWh) if day-ahead LBMP goes above the bid. Virtual transactions are scheduled in the day-ahead energy market only. In real time, virtual suppliers and virtual loads settle their day-ahead transactions by buying and selling, respectively, the amount of energy they were scheduled in day-ahead to provide or buy. Virtual transactions assist in the convergence of day-ahead and real time energy prices and hence increase market efficiency [5].

There has been abundant literature discussing the benefits and risk associated with virtual bidding. One such benefit is to increase market efficiency. If a day-ahead energy price is higher than real time energy price, virtual bidders will bid virtual supply in the day-ahead market and sell it back in real time. At equilibrium, day-ahead energy prices will converge to real time. The same is true if day-ahead energy prices are lower than real time; virtual bidders will bid virtual load and buy it back in real-time. This too tends to increase in market efficiency.

There have also been studies to discuss the manipulation of day-ahead prices by virtual bidding. A paper by John Birge [6] discusses virtual bidders and financial transmission rights (FTR) in MISO electricity market. It observes that during the time period between 2010 and 2012, the day-ahead prices were lower than real time prices but virtual bidders bought more energy than sold, hence sustaining negative profits for a time period longer than year. They observed a correlation between lower virtual profits at a node and larger FTR profits.

FTR correspond to the distribution of congestion revenues. Transmission line congestion between two nodes will correspond to the distribution of congestion revenue, directly proportional to the difference between LBMP's at the two nodes, to anyone holding FTR's for that transmission line. The paper by John [6] discusses about artificial transmission line congestion imposed by virtual bidders in order to manipulate the FTR profits

Another paper by Hogan [7] discusses price manipulation due to existence of multiple market clearing prices. Degenerate solutions to economic dispatch arise when the vertical segment of demand curve intersects with the vertical segment of aggregated supply curves. Any market clearing price within the degenerate range would satisfy the no arbitrage situation for any market participant, but would not send the right market signal. According to Hogan, the reported price would send wrong price signals to other supply or demand offers, and any small change in quantity of supply and demand would change market clearing prices by a lot with a small change in dispatch solution. In the context of this paper, demand curves can be price elastic virtual bids, which can result in a degenerate market solution, hence resulting in price manipulation.

CASE STUDY

In this section we present a case study to illustrate the impact of virtual transactions on day-ahead energy prices. Further we also demonstrate how the lumpiness in supply and demand curves can increase the frequency of the price spikes.

Let us assume a day-ahead energy market with five generators and three virtual bids and a physical hourly load of 290 MW. For simplicity, we assume no transmission line network, no reserves and no regulation requirements. It is straightforward to add complexities to the model once the framework is built. Table 1 shows the energy bids, minimum and maximum energy output for five generators and three virtual loads. Virtual loads bids are non physical financial transactions that bid in day-ahead energy market only.

Table 1. The Energy Bids Example

Generator/ Virtual Load	Minimum energy output (MW)	Maximum energy output (MW)	Energy bid ($/MWh)
G1	0	100	5
G2	0	100	10
G3	0	100	15
G4	0	100	20
G5	0	100	140
V1	-50	0	100
V2	-50	0	80
V3	-50	0	10

As seen in Table 1, we assume lumpy supply and virtual bids with G5 bidding substantially higher than other generating units and V3 bidding substantially lower than other virtual loads. Virtual loads will bid substantially higher if they want to get accepted in the day-ahead energy market, and bid substantially lower if they do not want to get accepted in the day-ahead energy market. With fewer virtual load bids, this behaviour will result in lumpiness in virtual demand curves. In general, the ISO solves a day-ahead security constrained unit commitment and a day-ahead security constrained economic dispatch to operate electric grid reliably and optimally [5]. In this paper, we assume G1, G2, G3, G4 and G5 are committed and we solve for the optimum generation dispatch to meet physical load and price elastic virtual load.

To solve for optimum generation dispatch we solve following optimization problem:

$$Min_{(P1,P2,P3,P4,Vl1,Vl2,Vl3)}\ Cg1\cdot P1 + Cg2\cdot P2 + Cg3\cdot P3 + Cg4\cdot P4 + Cg5\cdot Pg5 + Cv1\cdot Vl1 + Cv2\cdot Vl2 + Cv3\cdot Vl3$$

subject to

$$Pg1 + Pg2 + Pg3 + Pg4 + Pg5 + Vl1 + Vl2 + Vl3 = Load \qquad (1)$$

$$Pg1min \le Pg1 \le Pg1\max \qquad (2)$$

$$Pg2min \le Pg2 \le Pg2\max \qquad (3)$$

$$Pg3min \le Pg3 \le Pg3\max \qquad (4)$$

$$Pg4min \le Pg4 \le Pg4\max \qquad (5)$$

$$Pg5min \le Pg5 \le Pg5\max \qquad (6)$$

$$Vl1min \le Vl1 \le Vl1\max \qquad (7)$$

$$Vl2min \le Vl2 \le Vl2\max \qquad (8)$$

$$Vl3min \le Vl3 \le Vl3\max \qquad (9)$$

Where *Pg1, Pg2,Pg3, Pg4, Pg5* are the optimum generation schedules, *Vl1,Vl2,Vl3* are the optimum energy schedules that are purchased by virtual transactions, *Load* is the physical inelastic load, *Cg1,Cg2,Cg3, Cg4, Cg5* are the energy bids for five generators *Cv1,Cv2,Cv3* are the virtual load bids, *Pg1min, Pg2min, Pg3min, Pg4min,Pg5min* are the minimum generation levels, *Pg1max, Pg2max, Pg3max, Pg4max,Pg5max* are the maximum generation levels, *Vl1min, Vl2min, Vl3min* are the minimum energy levels that can be purchased by virtual loads, *Vl1max, Vl2max, Vl3max* are the maximum energy levels that can be purchased by virtual loads. The parameters for the case study are given in Table 1.

The objective is to maximize the social benefit by minimizing the total cost of generation. Equation (1) is the power balance equation and Equations (2)-(9) enforce the physical generating limits and limits on the energy levels that can be purchased by virtual loads. Table 2 gives the optimal generation schedules and optimal energy schedules purchased by virtual load bids. Energy price is then equal to the energy bid ($/MWh) of the marginal unit which is equal to the energy bid offer of the physical generator *G4* ($20/MWh).

Table 2. Generation and Virtual Transaction Schedules for 290 MW Load

Generator/ Virtual Bids	MWs cleared
G1	100
G2	100
G3	100
G4	90
G5	0
Vl1	-50
Vl2	-50
Vl3	0

Figure 1 shows the graphical interpretation of the market clearing process. Energy bids from generators are stacked from minimum to maximum. Corresponding to physical inelastic load of 290 MW, 100 MW of virtual price elastic load is met from the less expensive generators and G4 acts as marginal unit setting the energy price of $20/MWh.

Next, let us assume the hourly load increases by 20 MW from 290 MW to 310 MW. This increase in the load can be due to change in weather conditions. Let us now clear our day-ahead energy market with the net physical load of 310 MW.

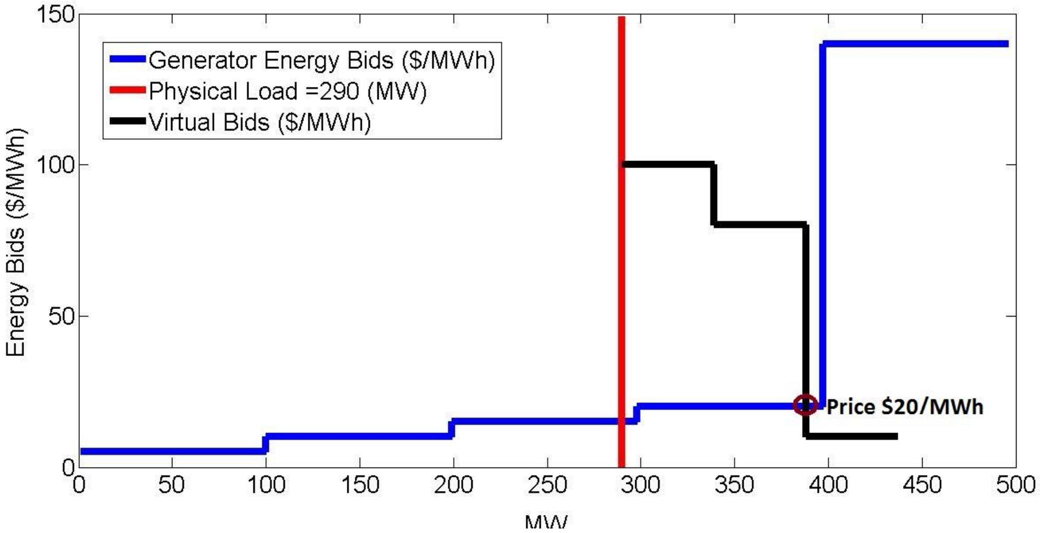

Figure 1. Market Clearing for 290 MW Load

Table 3 gives the optimal generation schedules and optimal energy schedules purchased by virtual load bids. Energy price is then equal to the energy bid ($/MWh) of the marginal unit which is equal to the energy bid offer of the virtual load *Vl2* ($80/MWh). Figure 2 shows the graphical interpretation of the market clearing process.

Table 3. Generation and Virtual Transaction Schedules
For 310 MW Load

Generator/ Virtual Bids	MWs cleared
G1	100
G2	100
G3	100
G4	100
G5	0
Vl1	-50
Vl2	-40
Vl3	0

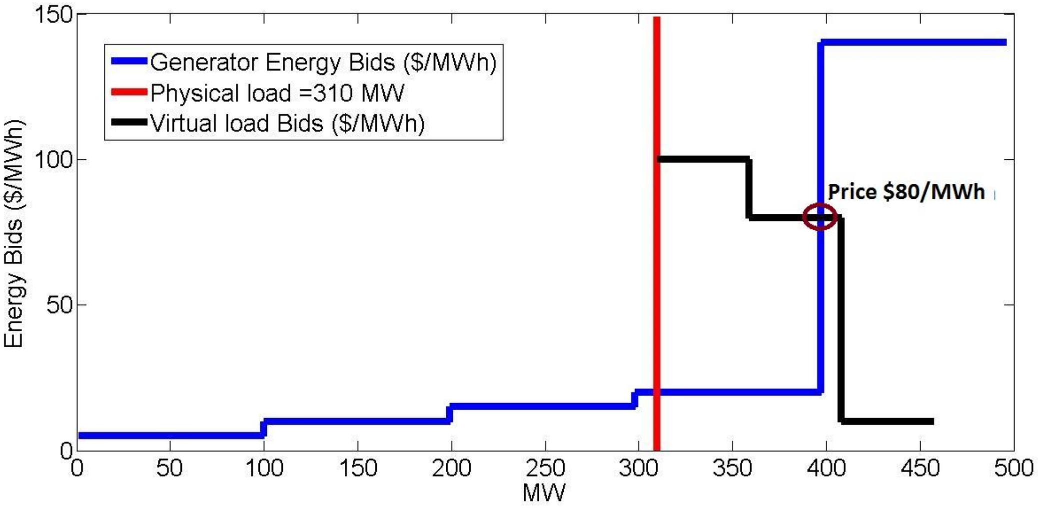

Figure 2. Market Clearing for 310 MW Load

With a slight increase in load from 290 MW to 310 MW, energy price increases from $20/MWh to $80/MWh. This is in particular due to lumpiness in energy supply curves and inclusion of virtual load bids in the day-ahead energy market. With no virtual load bids, price would only increase from $15/MWh to $20/MWh. This analysis highlights the ability of virtual transactions to set the day-ahead energy prices.

Load variations occur in real time on a daily basis, due to consumer behaviour and other factors. As seen in the case study, a small increase in load can result in high prices due to the interaction between lumpiness in supply curves and virtual transactions. Hence, virtual transactions can more frequently set the day-ahead energy prices if the supply curves are lumpy.

CONCLUSION

This paper has shown the impact of virtual transactions on day-ahead energy prices. It has demonstrated how the virtual load bids can cause a day-ahead energy price spike. In general, virtual transactions earn profits from the arbitrage between the day-ahead and real time energy prices. But, virtual traders can also set the day-ahead energy prices to increase their revenues. As an example, if a virtual trader also owns a generation facility, it can deliberately introduce a day-ahead energy price spike to yield profitable revenues for its generating utility. To mitigate this issue of price spikes due to virtual trading, more virtual transactions are necessary. This will reduce the lumpiness in supply curves and will reduce the discontinuity in day-ahead energy prices.

BIBLIOGRAPHY

[1] New England Training Course. “Energy Market Accounting Day-ahead and Real Time” http://sandbox.iso-ne.com/support/training/courses/wem101/12_energy_market_accounting_likover.pdf

[2] John Kwoka “ Price spikes in wholesale electricity markets: An update on problems and Policies”. InConference on Pressing Issues in World Energy Policy, 2012

[3] EIA “Wholesale electricity prices in Texas” http://www.eia.gov/todayinenergy/detail.cfm?id=6070

[4] FERC Office of the Chief Accountant, Office of Economic Policy, Office of Electric Power Regulation, Office of the General Counsel “Staff Report to the Federal Energy Regulatory Commission on the Causes of Wholesale Electric Pricing Abnormalities in the Midwest During June 1998” https://www.ferc.gov/legal/maj-ord-reg/land-docs/mastback.pdf

[5] Akshay Jha and Frank A Wolk “Testing for Market Efficiency with Transactions Costs: An Application to Convergence Bidding Electricity Markets” May 7 2013

[6] John Birge “Virtual Bidders and Financial Transmission Rights in the MISO Electricity Market”

[7] W. W. Hogan, “Multiple Market-Clearing Prices, Electricity Market Design and Price Manipulation,” The Electricity Journal, vol. 25, no. 4, pp. 18–32, May 2012. [Online].