Comparing Two-Settlement and Multi-Settlement Electricity Market Designs for Wind Integration: an Experimental Approach

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ABSTRACT

Wind power integration poses a challenge for U.S. electricity markets, which are based on a two-settlement structure. Wind production forecasts are generally less accurate in the day-ahead stage of the two-settlement structure, which may cause significant rescheduling costs in the real-time stage. We investigate whether a multi-settlement structure, with multiple intraday market stages, decreases system costs, relative to the two-settlement design. We develop laboratory experiments for both market designs, where participants act as power generators that sell electricity into the market. Optimization models are used to compare the performance of both market designs under varying levels of wind penetration.

BACKGROUND

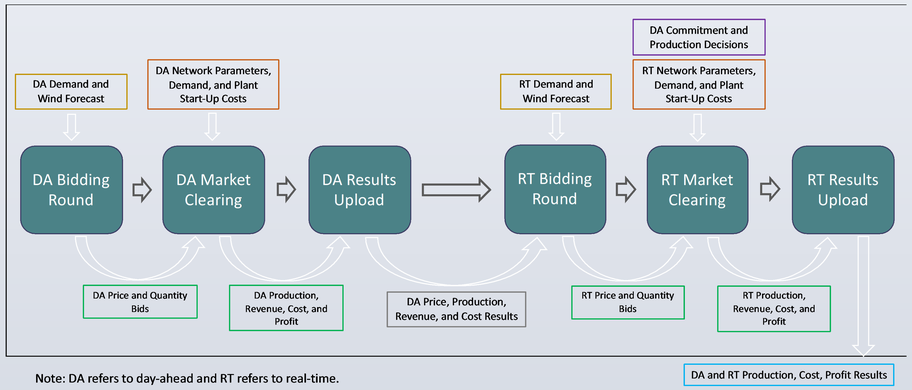
- U.S electricity markets are operated based on a two-settlement structure (2S) with day-ahead and real-time markets
- Under a 2S structure, inaccurate day-ahead wind forecasts may lead to an inefficient schedule of generating resources
- A multi-settlement structure (MS) in our experiment has two additional intraday markets which are cleared in between the day-head and real-time markets
- Under the MS structure, participants can re-trade their forward positions in intraday stages, which may decrease system costs and uplift payments relative to the two-settlement structure
- We run the experiment for three types of days, which represent different wind forecast profiles
- We use generator uplift as a measure of efficiency to compare the market performance of the 2S and MS designs

MOTIVATION AND RESEARCH OBJECTIVE

- Much of the research that investigates the comparison of 2S and MS design performance implements simulation modeling techniques
- Simulation modeling does not capture the real-world bidding behavior of electricity generating firms that participate in electricity markets
- Often these models assume that players are rational, and power plants offer electricity at their marginal cost with full generation capacity
- Additional assumptions include power plants having perfect information about electricity demand and wind production forecasts
- Instead, using an experimental economics approach may capture the real-world bidding behavior of generating firms in an electricity market setting
- **We use laboratory experiments to investigate the performance of the 2S and MS market structures with high wind penetration**

EXPERIMENTAL DESIGN

- Six human participants play the role of a wind generator that supplies electricity into a market for a given day
- Electricity demand at each node in the network is inelastic and known by all generating firms; a uniform price auction is used to balance supply and demand in each sample day
- Each participant is provided with an updated wind forecast at each stage and must produce their actual wind output at the final stage
- Each participant will only see its own wind forecasts, while all participants will be told the total expected or realized wind output

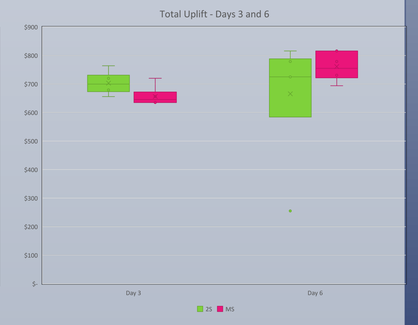


Note: DA refers to day-ahead and RT refers to real-time.

- ❖ This figure represents our experimental structure and shows the bidding and marketing clearing process for the 2S design
- ❖ Before the auction begins, day-ahead demand and wind forecasts are revealed to the players, who then submit price and quantity bids for the sample day
- ❖ Next, the system operator clears the day-ahead market using all supply bids
- ❖ Prices and quantities, as well as revenues, costs, and profits, are revealed to all players after the market clears
- ❖ In the real-time market, the updated real-time demand and wind forecasts are revealed to the players. A similar clearing process as in the day-ahead market is repeated

PRELIMINARY RESULTS

- ❖ Days 1-3 have the same wind and load profiles as Days 4-6 (day 1-day 4, day 2-day 5, day 3-day 6), but have been scaled up by a factor of 1.2
- On day 1 and day 4, MS is expected to have lower uplift than 2S. The experiment results show that the uplift was not significantly different on day 1, but the uplift was significantly smaller in MS on day 4
- On day 2 and day 5, MS is expected to have higher uplift than 2S. The experiment results show that the uplift was not significantly different on both day 2 and day 5
- On day 3 and day 6, MS and 2S are expected to have the same uplift. The experiment results show that the uplift was significantly smaller in MS on day 3, and there was no significant difference on day 6



DATA

- The experiments assume a high wind penetration with wind generation shares ranging from 20% to 40%
- There are different wind profile characteristics in each sample day
- Day 1 and day 4 have a decreasing linear forecast trend across market stages; day 2 and day 5 have inaccurate intraday wind forecasts; day 3 and day 6 have an increasing linear forecast trend across market stages
- Wind forecast information used in our experiments are adapted from ISO New England data
- Uplift is the main metric for evaluating market efficiency
- Uplift payments are out-of-market payments made to power plants to ensure adequate compensation when they are ordered to produce or reduce their power output

CONCLUSIONS

- Competitive benchmark results from a simulated model are used to compare with the data collected from the experiment
- Using these competitive benchmark results, we develop hypotheses for how the 2S and MS designs will perform in each sample day of the experiment
- We expect the MS design to have lower uplift in day 1 and day 4; we expect the MS design to have higher uplift in day 2 and day 5; we expect the MS design to have the same uplift in day 3 and day 6
- Our preliminary results show that uplift is not significantly different on day 1, day 2, day 5 and day 6 (contrary to our hypothesis)
- Our preliminary results show that uplift is significantly smaller in the MS compared to the 2S on day 3 (contrary to our hypothesis)
- Our preliminary results show that uplift is significantly smaller in the MS compared to the 2S on day 4 (in line with our hypothesis)
- Day 4 is the only sample day where our results are in line with our hypothesis
- More data collection is needed to finish our analysis of the performance of the 2S and MS structures with high wind penetration

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