THE WELFARE EFFECTS OF STRATEGIC STORAGE USE IN A DEREGULATED ENERGY MARKET

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Overview

In deregulated electricity markets, merchant storage operators act as both consumers and suppliers of electricity. Merchant storage operators consume electricity when prices are low and supply it when prices are high. Therefore, their profits are determined by the arbitrage opportunities that materialise within the wholesale market. When a merchant storage operator uses storage in a socially optimal manner, the full economic benefits from storage use can be extracted. The ability to manipulate prices will however give merchant storage operators an incentive to use storage devices strategically to widen the price spread and increase arbitrage opportunities. This strategy will however not allow the extraction of the full economic benefits from storage. Moreover, the manipulation of wholesale electricity prices could have social welfare implications that could be harmful to consumers and generators within the market. In the presence of start costs, these welfare implications are further complicated as the use of storage will also affect the decision to start or shut down a generating plant.

Thermal power plants generally burn some fuel to heat up the first head of steam for their turbines thereby incurring start costs in the process. Some power plants such as diesel generators have low start costs and can shut down and start up frequently throughout the day while others (like nuclear plants) have very large start costs and are only shut down in emergency situations or for scheduled maintiance. Therefore, during very low demand periods, generators with large start costs might be willing to pay to eliminate the possibility of having to shut down. To recover start costs, some wholesale market operators allow generators raise their bid price above their marginal costs. In other markets, generators are required to submit start cost separately from their energy bids. It has generally been acknowledged that greater grid flexibility has the potential to reduce the frequency of generator starts and the possibility of high electricity prices in the wholesale electricity markets. Energy storage devices can provide such flexibility by storing power in another form and transforming it back to electricity when required. Storage devices can also reduce the frequency of starts that generators experience. In addition to grid flexibility, energy storage operators can simultaneously provide other services such as balancing services, congestion relief and defer the need for transmission and distribution upgrades; however, this paper limits itself to the simpler case of pure arbitrage.

In this paper, a heuristic algothrim that incorporates the start cost of different generating plants is introduced and used to quantify the implication of strategic storage use in the British electricity market. Specifically, our analysis examines the impact of strategic storage use on the daily price profile and welfare in different generator dispatch environments.

Methodology

In our analysis, two optimization problems were solved. In the first optimization problem, daily social welfare was maximized through the optimal operation of a large storage device. In the second optimization problem, a large storage device is operated to maximise storage operator profits. To account for generator behaviour under different market environments, dispatch constraints were used to control the volume of power dispatched by each generator. This allowed us to impose the first order conditions from the generators' optimisation while optimising for the storage operator. These conditions also allowed for the merit order dispatch of generators.

Start costs were incorporated through a heuristic algorithm that allowed each plant to spread the recovery of start costs throughout the day by adding them to their hourly bids. Using load data, the algorithm calculated the number of hours that the marginal generator would be online and the number of hours it would be offline over a period of 24 hours. In hours for which the marginal generator would be online for fewer than 12 hours during the day, start cost of online generators were divided by the number of hours such generators were online and this was added to the marginal cost of each generator type. For hours in which the marginal generator would have been offline for fewer than 12 hours during the day, stopping was penalised by subtracting the start cost that would be incurred in a later start from the generator's marginal cost. Once again, the heuristic divides the start cost by the number of hours the plant would be offline before subtracting it from the marginal operating cost of the generator.

To save on computational time, 150 clusters of days were generated from our hourly time series of hourly net demand. Each cluster represented 24 hours of demand that simulated a typical day from within it. Storage use was then optimized for each representative day and the average equilibrium price for a typical day was generated. In addition, consumer surplus, producer surplus, storage profits and welfare were calculated by attaching weights to each compent. These weights represented the number of times each representative day occurred in a year .

Results

The socially optimal use of storage resulted in a price smoothening effect. It raised the price of electricity in periods of low demand by an average of 4% and reduced the price of electricity in periods of high demand by an average of 9%. The strategic use of storage dampened the price smoothening effect. When storage was used strategically, the price of electricity in low demand periods went up by an average of 0.4% while the price of electricity in high demand periods went down by an average of 6.6%. In a strategic dispatch envrironment, the socially optimal use of storage was able to eliminate the high afternoon peak prices and lower the evening peak prices. As storage discharged power during periods of high demand, generators were forced to re-evaluate their production plant. When the power rating was high enough, prices during peak demand hours were eliminated as more peak shaving was provided in this period.

Overall strategic storage use had minimal impacts on the welfare to turnover ratio. Strategic storage use however led to some transfers between consumers, storage operators and generators. In all dispatch environments, strategic storage use reduced consumer surplus and increased storage profits in all market environments. Strategic storage use raised generator profits in a competitive storage dispatch environment. Generator profits however declined when generators were dispatched strategically and the power rating of storage was high enough. In a strategic dispatch environment, strategic storage use prevented significant reductions in marginal cost in a bid to widen the price spread between low and high demand period. This caused lower generator profits as generators had to dispatch high cost plant in high demand periods. This resulted in lower generator profits during strategic use of high enough levels of storage.

Conclusions

As more renewable energy resources are deployed into the energy market more flexibility will be required for their effective integration. This paper shows that storage has the potential to provide this flexibility. However, if storage operators are allowed to develop market power, the benefits from their presence will be greatly reduced. Fortunately, most new storage technologies come in relatively small units, allowing for the presence of many different operators without significant market power. The scenario that we have modelled, with a monopoly in storage, might be regarded as extreme. Even so, the argument that storage can bring significant benefits to the transmission system (not modelled here) might be used to argue that the transmission operator should be given a monopoly over it. This paper shows that creating a storage operator with market power would risk significant welfare losses. By keeping storage in the competitive parts of the electricity market, the incentive for significant market manipulation by large storage facilities would be mitigated and the full economic benefits of these devices extracted.