**Estimating Arbitrage Profits for Storage Resources in Nodal Electricity Markets:**

**A Decision Tree Method**

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## Overview

As the share of power generation from intermittent wind and solar plants is projected to grow in the coming decades, there is increasing recognition among industry participants that a variety of low-carbon power storage resources will also grow to manage this intermittency. There remain, however, ongoing discussions about the profitability of these storage resources and at what point market conditions will support widespread investment in utility-scale storage applications. In most restructured wholesale power markets, the profitability of a storage resource will depend on its ability to arbitrage intraday price differences by purchasing power at low prices and selling it at higher prices.

In this paper, we propose a decision tree method to estimate a storage resource’s expected profit and the corresponding probability distribution of this profit in a nodal power market. We first formulate a mixed-integer optimal charge/discharge/idle problem for a storage resource that wants to maximize profits over time. We model nodal prices as a discrete Markov chain process. We estimate transition probabilities using the historical price data. We assume that the nodal price applicable for a time interval is known to the storage operator at the beginning of the time interval. At the beginning of every time interval, the storage operator’s decision to charge, discharge, or remain idle is based on known price for that time interval and conditional probability distribution of prices for the subsequent time intervals. We solve the storage operator’s problem to find a sequence of charge/discharge/idle decisions that maximizes the profit given the capacity of the storage resource. The unconditional probabilities of all feasible sequences of charge/discharge/idle decisions are used to derive the profit distribution. We use this method to compute the optimal profit and profit distribution for a representative set of generation pricing nodes in the nodal electric power market operated by the Midcontinent Independent System Operator (MISO). The optimal profit and profit distributions generated by this model could be used to potentially identify the optimal locations for installing storage resources given an individual investor’s risk-reward preferences.

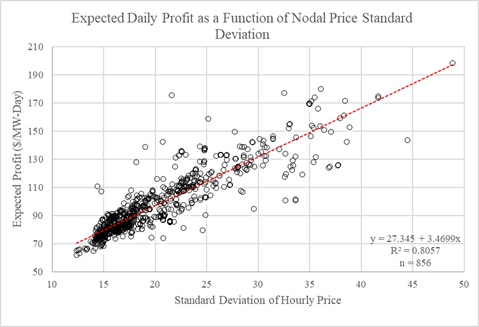
## Methods

The storage operator’s problem presents a formidable computational challenge. The number of decision points increase exponentially with the number of price states. For example, there are 2.2x1021 decision points in a 24 hour problem involving seven discrete price states. We break down the storage operator’s problem into multiple sub-problems using Bellman equations and solve recursively to obtain the optimal sequence of charge and discharge decisions. We formally prove that the global optimum obtained from solving the single undivided problem is identical to the optimum obtained through recursively solving the multi-state problem using Bellman equations.

We use this model to calculate the expected profits and corresponding profit distributions at generation nodes in MISO. We use historical real-time, hourly prices between 2017 and 2020 to estimate transition probabilities. We begin with a full sample of all 1,586 generation nodes but exclude nodes with insufficient history, i.e., nodes with fewer than 50% of the total possible number of 35,064 hourly observations. We also choose one representative node for each group of duplicate nodes that we identify as having identical prices. Duplicate nodes typically occur when several nodes are assigned to individual turbines or reactors located at one power plant. This leaves us with 856 unique nodes for our final analysis.

To enhance the precision of our analysis, we run the model for all 856 generation nodes by sorting the price data into eight different seasonal groups. First we sort the data into the four seasons of the year; winter, spring, summer, and fall. We then subdivide each of these groups into two separate groups; weekdays and weekends/NERC holidays.

## Results

The preliminary results of our analysis show several interesting patterns.[[1]](#footnote-1) First, there appears to be a strong, positive correlation between the standard deviation of prices and expeted profit at a given node: generation nodes that exhibit high standard deviations tend to also yield high expected profits. Similarly, there is a strong, positive correlation between the price range and expected profit at a given node. These results are consistent across both summer and winter weekdays. The figure to the right shows the relationship between the standard deviation of hourly prices and the corresponding expected profit at each node during the summer weekdays. We include a simple linear regression model estimated using OLS that yields an R-sqaured value of 0.806.

We also observe several interesting patterns in node profitability that may be more specific to the MISO market. After ordering all 856 nodes from highest to lowest expected profit, the most profitable nodes appear to be clustered in specific geographic areas of MISO. Of the hundred most profitable nodes, almost all were located in one of three market subregions: the Entergy Electric System (EES) service territory in Louisiana and Texas; Load Resource Zone 7 which covers Detroit Edison (DTE) and Consumers Energy (CONS) territory in Michigan and the eastern portion of Load Resouce Zone 2 that covers Michigan’s Upper Peninsula and; Load Resource Zone 6, which covers the state of Indiana. This result was consistent aross both the winter and summer seasons: seventy-eight and seventy-six of the one hundred most profitable nodes during the winter and summer seasons were located in these three geographic regions of MISO.

We postulate that the clusters of highly profitable nodes in these three market subregions may be a result of their proximity to neighboring market areas. Unscheduled loop flows and other interface modelling issues have been identified between MISO and the Texas wholeslale market (ERCOT), PJM Interconnction, the Tennessee Valley Authority (TVA), and the Ontario wholesale market (IESO). Several sources have identified market volatility in the MISO as a result of transmission line loading relief procedures (TLR) used to manage interface flows between MISO and these adjoining balancing areas [1,2]. If these interface issues are indeed driving the volatility at many of the most profitbale nodes then there is an important lesson for potential investors to be aware of: changes in network topography, market rules, or physical/commercial flow modelling across market interfaces may change the future profitability of a given market location.

## Conclusions

In this paper, we have formulated an optimal scheduling problem for a storage resource operator who wishes to maximize profits over a long time horizon. We used this method to estimate a storage resource’s profit potential for every representative pricing node in the MISO wholesale electricity market.

Our preliminary results show that the expected profitability for a storage resource exhibts a strong, positive correlation with the standard deviation of the nodal price distribution. This result is consistent with classical models of finance and option pricing theory where higher levels of price volatility allow for greater arbitrage opportunities for market participants. Our preliminary results further show that the spatial distribution of the highly profitable pricing nodes is largely consistent with the underlying factors that contribute to the intraday volatility of nodal prices in MISO. The results show that nodes in the vicinity of congested transmission facilities and interfaces with neighboring power markets have relatively higher profit potential. We also identify the most profitable nodes located at large intermittent generating resouces.

## References

[1] Potomac Economics LLC., (2020). “2019 State of the Market Report for the MISO Electricity Markets.” June 2020.  
<https://www.potomaceconomics.com/wp-content/uploads/2020/06/2019-MISO-SOM_Report_Final_6-16-20r1.pdf>.

[2] Miller, Rebecca (2020). “NERC Reliability Procedures and Real-Time Volatilty in MISO.” Genscape.   
<https://www.genscape.com/blog/nerc-reliability-procedures-and-real-time-volatility-miso>

1. At the time of the submission of this abstract, we have completed the analysis for the summer and winter weekday time periods. [↑](#footnote-ref-1)