Battery Storage Arbitrage Valuation
A Model Brief

1. Introduction

Batteries can serve as both instantaneous generation and instantaneous load, making them a unique energy asset. Their flexibility allows for the deferral of generation and transmission capacity, the provision of regulation services, and the facilitation of price arbitrage. These features add complexity to the valuation model for batteries.

In our opinion, the first and most fundamental step in valuing a battery must consider the arbitrage value component based on transparent forward price curves and widely accepted real option concepts.

2. Model Application

Battery option models fall into two main categories.

The first category of battery valuation model generally encompasses factors and dynamics more interesting to utilities, battery vendors, and end-users. These models emphasize the variety of competing uses for batteries, which may include such items as frequency regulation, spinning reserves, resource adequacy, congestion relief, and demand charge reduction.

The second category of battery valuation model, and the one which this paper highlights, considers the option value of the battery from the perspective of a commodity merchant who engages in arbitrage. From this perspective, we envision a scenario in which an originator brings a prospective battery transaction to a structure desk that must perform an analysis permitting the merchant to value and hedge as much risk in the battery as possible. Here the focus lies in producing transactable hedges, as well as calculating the mark-to-market and value-at-risk in the transaction.

3. Model Description

In a nutshell, the following are the key properties of the model methodology.

- Backward induction valuation on a 24-hour horizon using trader marked underlyings, volatilities, correlations and day ahead shape factors
  - Monthly valuation and hedges achieved by permitting both weekday and weekend shapes and inputting the number of weekday days and the number of weekend days and then aggregating the different 24-hour solutions.
- The backward induction (Bellman) is situated on top of discretized battery inventory states, which are variable and permit more or less granularity.
- Stochastics are imposed using a 2-factor Gaussian quadrature on the forward underlyings, volatilities, correlations and DA shapers. The hourly stochastics are realized through shocks to the 2 underlyings (on peak and off peak). The hourlies themselves are not shocked on their own in an hourly spot process.

4. Model Example

An illustration of the model setup and the results are shown below. The specifics of the battery are characterized by 4 variables: the capacity (100 MW), the charge (10 MW/h) and discharge (25 MW/h) speeds, and the efficiency (80 percent).

MODEL INPUTS

Curve Data	1/1/19	2/1/19	3/1/19	4/1/19	5/1/19	6/1/19	7/1/19	8/1/19	9/1/19	10/1/19	11/1/19	12/1/19
5x16	49.45	36.70	36.68	35.89	34.93	45.42	70.90	71.27	39.77	34.49	34.94	36.80
2x16	42.24	41.17	40.87	29.55	31.28	38.17	67.58	67.28	31.23	26.01	26.36	27.18
OffPeak	32.61	31.77	25.37	18.34	19.64	18.54	19.98	19.89	21.83	18.17	18.41	18.98
5x16 Vol	0.50	0.50	0.50	0.50	0.50	0.80	0.90	0.80	0.50	0.50	0.50	0.50
2x16 Vol	0.48	0.48	0.48	0.48	0.48	0.78	0.88	0.78	0.48	0.48	0.48	0.48
OffPeakVol	0.40	0.40	0.40	0.40	0.40	0.70	0.80	0.70	0.40	0.40	0.40	0.40
5OffCorr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
2OffCorr	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
TotDays Wkday	22.00	20.00	21.00	22.00	22.00	20.00	22.00	22.00	20.00	23.00	20.00	21.00
TotDays Wknd	9.00	8.00	10.00	8.00	9.00	10.00	9.00	9.00	10.00	8.00	10.00	10.00
r	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Asset Data												
Inventory Nodes	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
DisChg Capacity MWh	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
ChargeSpeed (MW/Hr)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
DisChargeSpeed(MW/Hr)	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Efficiency	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80

The results for this setup take about 1 minute to calculate and it is trivial to try other input constellations. The model is built in C# and implemented in a formatted workbook. The results of this example result in a total margin value of $1,573,886 pertaining to arbitrage option value.

MODEL RESULTS: Margins and Deltas

	1/1/19	2/1/19	3/1/19	4/1/19	5/1/19	6/1/19	7/1/19	8/1/19	9/1/19	10/1/19	11/1/19	12/1/19
WkDay Margin	$52,464	$30,818	$36,653	$51,323	$55,640	$90,757	$511,749	$161,684	$67,036	$54,649	$39,793	$44,488
Wknd Margin	$14,042	$12,447	$18,505	$15,465	$20,778	$30,882	$141,299	$60,719	$24,848	$13,478	$11,945	$12,424
Total Margin	**$66,506**	**$43,265**	**$55,158**	**$66,788**	**$76,418**	**$121,639**	**$653,048**	**$222,404**	**$91,884**	**$68,127**	**$51,738**	**$56,912**
5x16 Delta	0.8562	0.5087	0.7588	0.9385	1.0117	1.1936	3.2516	1.1803	1.0704	0.9236	0.7909	0.7910
2x16 Delta	0.7092	0.6735	0.7849	0.9017	0.9909	1.0221	2.4110	1.1621	0.9628	0.7768	0.6221	0.6193
OffDelta	(0.5278)	(0.1753)	(0.4450)	(0.5201)	(0.4770)	(0.4621)	(0.0114)	(0.5338)	(0.3502)	(0.3746)	(0.3580)	(0.3575)

It is possible to achieve deltas that are greater than one depending on the shape factors and the charge and discharge speeds relative to the capacity. In other words, under certain conditions inside a single discrete time period, the battery can fully discharge, recharge, and then discharge again, hence achieving a delta that exceeds one.

The model also produces probabilistic hourly positions for both a representative weekday and a representative weekend day.

MODEL RESULTS: Probabilistic Hourly Positions

	1/1/19	2/1/19	3/1/19	4/1/19	5/1/19	6/1/19	7/1/19	8/1/19	9/1/19	10/1/19	11/1/19	12/1/19
WeekdayHE1	11.1	11.1	11.1	11.1	11.0	7.6	3.6	10.7	9.4	10.7	11.1	11.1
WeekdayHE2	11.1	11.1	11.1	11.1	11.1	11.1	6.8	11.0	11.1	11.1	11.1	11.1
WeekdayHE3	11.1	11.1	11.1	11.1	11.1	11.1	10.9	11.1	11.1	11.1	11.1	11.1
WeekdayHE4	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
WeekdayHE5	11.1	10.8	11.0	11.1	11.1	10.8	10.3	10.9	11.0	10.7	10.3	10.1
WeekdayHE6	9.5	(11.9)	4.2	9.8	7.4	11.4	(1.3)	10.4	7.2	6.1	5.8	5.8
WeekdayHE7	(26.0)	(25.1)	(25.8)	11.1	11.1	11.3	11.2	11.1	11.1	11.1	(25.1)	(24.9)
WeekdayHE8	(24.8)	(6.2)	(20.1)	9.0	9.4	9.2	10.9	9.0	9.3	9.2	(21.0)	(20.9)
WeekdayHE9	11.1	11.1	11.1	11.2	11.2	11.1	11.4	11.2	11.3	11.3	11.1	11.1
WeekdayHE10	11.1	11.1	11.1	11.1	11.1	11.2	11.8	11.1	11.1	11.1	11.1	11.1
WeekdayHE11	11.1	11.1	11.1	2.6	3.5	3.5	8.0	2.6	3.5	3.6	11.1	11.1
WeekdayHE12	11.1	11.1	11.1	0.4	1.5	0.5	6.9	0.4	1.6	1.6	11.1	11.1
WeekdayHE13	13.2	12.7	13.1	0.4	0.4	0.5	5.6	0.4	1.6	1.6	13.3	13.3
WeekdayHE14	11.1	11.1	11.1	(21.8)	(21.6)	0.4	4.0	0.1	0.5	0.4	11.1	11.1
WeekdayHE15	11.1	11.1	11.1	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(25.9)	11.1	11.1
WeekdayHE16	11.1	11.1	11.1	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	11.1	11.1
WeekdayHE17	11.1	11.1	11.1	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	11.1	11.1
WeekdayHE18	(26.0)	(26.0)	(26.0)	(0.1)	(0.2)	(21.6)	(21.1)	(21.9)	(21.5)	(21.3)	(26.0)	(26.0)
WeekdayHE19	(26.0)	(26.0)	(26.0)	0.4	1.6	1.0	7.1	0.4	1.6	1.6	(26.0)	(26.0)
WeekdayHE20	(26.0)	(25.1)	(25.8)	11.1	11.1	1.6	9.0	0.5	2.2	11.1	(25.7)	(25.7)
WeekdayHE21	(20.7)	(0.9)	(16.6)	(9.6)	(7.7)	2.2	9.0	1.0	3.3	(6.9)	(17.2)	(17.2)
WeekdayHE22	4.0	9.5	4.2	1.6	4.0	2.2	9.5	1.5	4.0	4.0	4.0	4.0
WeekdayHE23	(4.2)	(18.7)	(6.2)	(2.1)	(5.9)	(4.8)	(21.4)	(2.6)	(7.9)	(5.9)	(5.9)	(5.9)
WeekdayHE24	(0.3)	(8.3)	(2.0)	(0.2)	(1.3)	(1.8)	(10.0)	(0.6)	(2.3)	(2.3)	(2.5)	(2.6)
WkndDayHE1	8.5	7.6	8.5	7.2	5.7	7.2	8.7	8.1	5.5	5.5	6.1	6.1
WkndDayHE2	11.1	11.1	11.1	10.6	9.9	10.6	10.4	10.9	9.4	9.0	11.1	11.1
WkndDayHE3	11.1	11.1	11.1	11.1	11.0	9.9	11.0	11.0	10.7	10.7	11.1	11.1
WkndDayHE4	11.1	11.1	11.1	11.1	11.1	10.6	11.0	11.1	11.1	11.1	11.1	11.1
WkndDayHE5	11.0	9.9	10.9	11.1	11.1	11.1	10.6	11.1	10.2	11.1	5.7	5.7
WkndDayHE6	12.2	11.8	12.9	12.8	12.4	11.9	8.3	12.8	11.0	10.8	8.5	8.4
WkndDayHE7	11.1	11.3	11.2	11.5	11.8	11.2	11.2	11.3	11.6	11.6	11.4	11.4
WkndDayHE8	9.0	9.2	9.0	9.3	9.8	9.3	9.7	9.1	9.9	10.0	9.6	9.6
WkndDayHE9	(24.8)	(24.3)	(25.5)	11.1	11.1	11.2	11.3	11.1	11.2	11.1	(18.8)	(18.8)
WkndDayHE10	(25.3)	(23.7)	(25.5)	11.1	11.1	11.1	11.2	11.1	11.1	11.1	(19.1)	(18.9)
WkndDayHE11	11.1	11.1	11.1	4.0	5.4	4.0	4.0	3.0	5.7	5.6	11.1	11.1
WkndDayHE12	11.1	11.1	11.1	0.1	0.5	1.0	1.6	0.1	1.6	1.6	11.1	11.1
WkndDayHE13	11.4	11.4	11.2	0.0	0.1	1.0	1.6	0.1	1.0	0.5	11.5	11.5
WkndDayHE14	11.1	11.1	11.1	(19.7)	0.0	0.4	0.5	0.1	0.5	(14.3)	11.1	11.1
WkndDayHE15	11.1	11.1	11.1	(26.0)	(26.0)	(25.8)	(26.0)	(26.0)	(25.9)	(24.8)	11.1	11.1
WkndDayHE16	11.1	11.1	11.1	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	11.1	11.1
WkndDayHE17	11.1	10.8	11.0	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	(26.0)	9.5	9.5
WkndDayHE18	(26.0)	(26.0)	(26.0)	(2.1)	(21.9)	(21.3)	(21.5)	(21.9)	(20.8)	(6.2)	(26.0)	(26.0)
WkndDayHE19	(26.0)	(26.0)	(26.0)	11.1	2.2	1.0	2.2	0.4	3.8	11.1	(26.0)	(26.0)
WkndDayHE20	(26.0)	(25.8)	(26.0)	11.1	3.5	1.6	3.5	0.5	4.2	11.1	(25.1)	(25.1)
WkndDayHE21	(14.8)	(13.7)	(16.9)	(15.7)	0.0	2.2	4.2	1.0	5.6	(8.9)	(8.9)	(8.9)
WkndDayHE22	7.6	7.1	3.5	4.0	4.0	2.2	4.2	1.0	7.1	6.9	5.6	5.6
WkndDayHE23	(9.1)	(8.8)	(3.7)	(5.8)	(6.5)	(4.8)	(9.5)	(2.1)	(13.7)	(11.9)	(10.0)	(10.0)
WkndDayHE24	(1.5)	(2.6)	(0.7)	(2.2)	(2.2)	(1.8)	(3.5)	(0.5)	(5.7)	(6.2)	(5.9)	(5.9)

Note that efficiency is loaded onto the charge positions both in the backward induction and in the publication of the charge positions.

5. Model Extensions

There are a number of ways to extend the model into more complicated situations. However, some of these might be accomplished by simply modifying the shape factors. For instance, if the asset is targeted at specific locational peak shaving in August, one could take the shape factors for those hours to a non-market level guaranteeing that model dispatches those hours and captures the non-market valuation for those hours. Remaining battery constraints would remain in place in the model.

Jointly capturing energy regulation values (ancillaries) with the model is of course possible but complicating. The backward payoff function would require additional factors and constraints (like not permitting energy arbitrage discharge and the sale of UpReg for the same hour). In the end we'd have to leave the speed of the Gaussian quadrature and impose, we think, Least Squares Monte Carlo methods.

6. Project Economics

Taking a step back from the specific valuation problem heretofore discussed, one needs to consider the rate-of-return economics for utility-scale batteries. Assuming costs of approximately $1,500 per kW,[1] how does the previously calculated $1,573,886 annual option value of the arbitrage component perform?

Keeping with this article's 100MW example, that translates into a $150 million capital cost. Simple arithmetic results in a 95.3-year payback period.[2] Judging by this simple payback measure, the rates-of-return based solely on wholesale arbitrage opportunity are severely lacking. In the current market environment, rationalization of utility-scale batteries must obviously rely heavily on areas of value other than arbitrage. Even in the context of those rationalizations, however, are batteries still too expensive when compared to more traditional flexible gas-fired power generation combined with dedicated natural gas storage? Batteries must definitively answer that question before widespread adoption.

7. Contact

Contact either Mark Houldsworth or Rich Pastore with any questions you have or if you'd like to see a demo of this or one of our other models. We're happy to customize any of our models for our clients' specific needs.

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[1] EIA, U.S. Battery Storage Market Trends, p. 12.
https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

[2] $150 million capital cost ÷ $1,573,886 per year = 95.3 years.