Energy Storage: How Realistic is a Once per Day Cycle Assumption?

This article uses the following acronyms
5MM = Five-Minute Market | CAISO = California Independent System Operator | DAM = Day-Ahead Market | FMM = Fifteen-Minute Market | HE = Hour Ending | IRR = Internal Rate of Return | LMP = Locational Marginal Price | NP15 and SP15 = North of Path 15 and South of Path 15 | PPA = Power Purchase Agreement | RTM = Real-Time Market | SOC = State of Charge

There is no shortage of asset owners and project developers studying the economics of battery storage – especially in California. GridSME and its clients are no exception. We are constantly trying to answer questions like, "What is the value of a battery energy storage system ("BESS" or battery for short)? What is the optimum location, size, and duration? What market products are best-suited for a battery? What market products can be stacked together?" The opinions, speculation, and analysis lead to a number of different answers. The one area where there seems to be consensus is around the belief that in today's market a four-hour battery could and should, on average, cycle once per day. In other words, a four-hour battery[1] will, in the aggregate, go from empty-to-full-to-empty 365 times per year.

Spoiler alert. We're talking about this because we think that assumption is flawed – at least in today's market. If your battery is tied to a PPA with time-of-delivery factors, then yes, cycling once per day is a no-brainer. What we're referring to is a battery generating profit through energy arbitrage in the wholesale electricity markets (e.g., CAISO). At first glance, it's easy to see why the default assumption is a full once per day cycle pattern. If we look at 2018 CAISO energy prices for SP-15 (Figure 1), it's easy to see the arbitrage potential. Charge from HE11 to HE14 and discharge from HE18 to HE21. Simple as that, right? Not quite. As we see it, several factors hinder a full once per day cycle pattern:

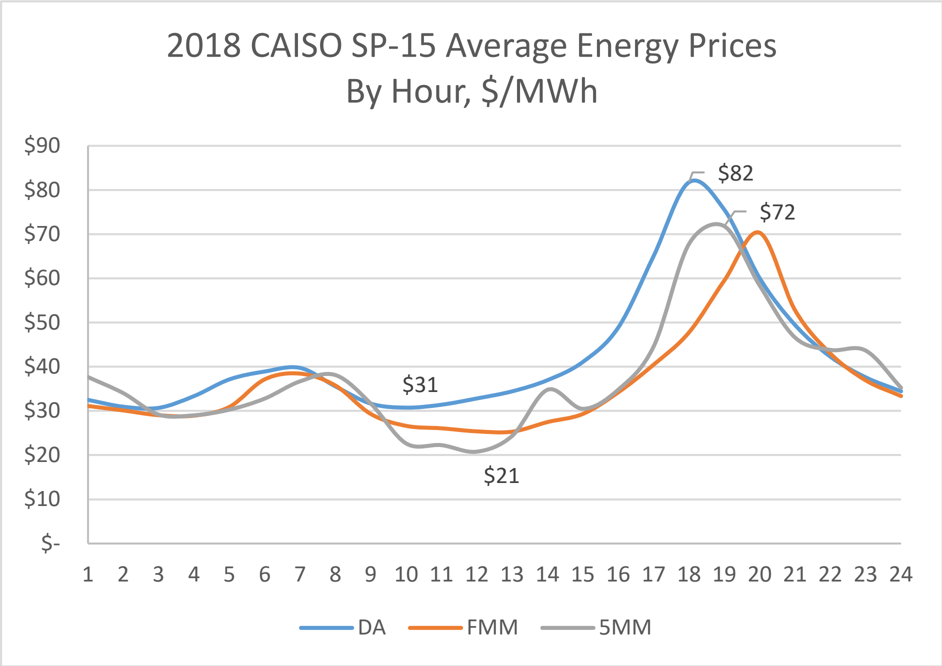

Figure 1: 2018 CAISO SP-15 Avg Energy Prices

[1] In this post, any reference to battery assumes a four-hour battery.

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1. **The opportunity cost of a cycle** (i.e., the spread between charge and discharge prices must be adequate to cover the opportunity cost)
2. **Average prices are just that** – expect plenty of days when the low-to-high price variance will be small or the timing of peaks and troughs will deviate from the norm
3. **We cannot rely on perfect foresight** – for multiple reasons, a battery cannot expect to always charge at the lowest daily prices and discharge at the highest daily prices
4. **Incremental / decremental awards** – a financially binding award in the DAM or FMM does not guarantee real-time dispatch and physical battery operation *(which is a good thing)*

First, let's start with the **opportunity cost of a cycle (reason #1)**. Assuming each battery cycle causes some level of degradation and brings the asset one step closer to replacement, it doesn't make sense to charge at any price lower than the discharge price. There must be a sufficient spread between charge and discharge prices to make cycling economic. Let's make a couple more assumptions. Assume a $200/kWh battery replacement cost, a 10% cost of capital, a 10% efficiency factor, a 7,300-cycle useful life, and a 50% salvage value. That equates to an opportunity cost of approximately $26/MWh per cycle.

Averages are just that (reason #2) – they are not day-by-day certainties. We have the benefit of hindsight to see where the troughs and peaks *were*. The past is no guarantee where these peaks and troughs will occur tomorrow. If a resource operator assumes it can just self-schedule to charge and discharge the battery during these historical peak and trough hours, that equates to only $47/kW-year for 2018[2] – not quite the $80+/kW-year price many storage enthusiasts are hoping to see from energy arbitrage, and the amount likely required to make battery projects' IRR sufficient.[3] Of course, we can expect volatility to increase in the future, but project financing can't rely too much on forecasts and predictions. It must also rely on sound strategies that maximize returns given the opportunity set.

We cannot rely on perfect foresight (reason #3) – certainly, if one was able to accurately predict when the price peaks and troughs were to occur, it could self-schedule the battery in the real-time market to charge and discharge during outlier intervals. The battery operator, whether human or computer, would manage the SOC to allow room for upcoming price extremes. But perfect foresight isn't possible. There will undoubtedly be times when price extremes occur and the battery's SOC prohibits its operation. In addition, assuming the battery is self-scheduled during the "known" extreme intervals, it would not necessarily capture the price extremes for the following reason. If a battery is self-scheduled in the real-time market, it will settle at the FMM price, and not the 5MM price. Often (but not always), the higher volatility and more extreme outlier prices are seen in the 5MM. A resource only settles at the 5MM price when it receives a 5MM award different from its FMM award or when there is an imbalance between its meter and its 5MM award. Therefore, the battery must be submitting economic (i.e., price sensitive) bids

[2] Using 2018 SP-15 DAM average energy prices.
[3] The Brattle Group. Stacked Benefits: Comprehensively Valuing Battery Storage in California. September 2017.

in the real-time market if it wishes to consistently capture 5MM price extremes.

And finally, **incremental/decremental awards (reason #4)** in the real-time market will often bring the battery's real-time dispatch to zero. We frequently see battery revenue modeling done through an analysis of LMP data sets. Daily high and low prices are identified, the buy-sell arbitrage spread is calculated, and a "margin of safety" haircut is applied to arrive at an estimate of achievable energy arbitrage revenue potential. And it is assumed the battery will physically charge and discharge during those price peak and trough intervals. Using this modeling method, what goes overlooked is a financially-binding award in the DAM or FMM does not guarantee the battery will receive a physical real-time dispatch signal for that time interval. Let's walkthrough an example.

First, assuming the battery economically bids its load and generation energy in the market, the bids and awards in Table 1 below take place in the DAM:

Market	Bid Qty	Bid Price	Market Price	Awarded Qty	Settlement
DAM Energy	-40	$8	$47	0	$0
DAM Energy	0	$45	$47	0	$0
DAM Energy	+40	$45	$47	+40	$1,880

Table 1: DAM settlement for the full hour

Following this DAM award, let's assume the battery continues to wisely submit economic energy bids to the RTM, which consists of both the FMM and 5MM. The FMM is run and the bids and awards are shown in Table 2.

Market	Bid Qty	Bid Price	Market Price	Awarded Qty	Settlement
FMM Energy	-40	$20	$57	0	$0
FMM Energy	0	$45	$57	0	$0
FMM Energy	+40	$45	$57	+40	$0

Table 2: FMM settlement for one 15-minute interval within that hour

The FMM price stayed at or above the battery's bid price, so its FMM award was no different from its DAM award – therefore, no settlement. But this same bid will be part of the 5MM run the battery's 5MM award and real-time dispatch can vary if the 5MM price falls, as shown in the example in Table 3 below.

Market	Bid Qty	Bid Price	Market Price	Awarded Qty	Settlement
5MM Energy	-40	$20	$30	0	$0
5MM Energy	0	$45	$30	0	<$100>
5MM Energy	+40	$45	$30	0	$0

Table 3: 5MM settlement for one 5-minute interval within that hour

The 5MM price falls below the battery's RTM generation bid price but above its load bid price, resulting in a 5MM award and real-time dispatch of zero MWh's – meaning the battery "buys back" the 40 MWh's from the market for this 5MM interval. And therefore, the battery has no physical operation during this interval. But this isn't a bad thing because it means the battery is accruing arbitrage revenue without a physical operation.

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Let's look at another example illustrating why a battery is not likely to cycle once per day. Figure 2 below depicts a historical day's energy prices in 2018 for a specific Northern California Pnode. On this day, which is a pretty typical winter day, there are 62 five-minute intervals where the FMM or 5MM price is below a hypothetical battery charge-discharge price band.[4] And there are 30 five-minute intervals where the FMM or 5MM price is above a hypothetical charge-discharge price band. For a full daily cycle, a four-hour battery would need to charge in at least 48 five-minute intervals and discharge in at least 48 five-minute intervals. So, for this particular day, a full cycle would not be economic or necessary. Applying the hypothetical battery charge-discharge price band for this particular NP-15 Pnode to all of 2018, there were 266 days that contained 48 or more five-minute charge intervals and only 125 days that contained 48 or more five-minute discharge intervals. Certainly not indicative of price spreads adequate to justify a full once per day cycle pattern.

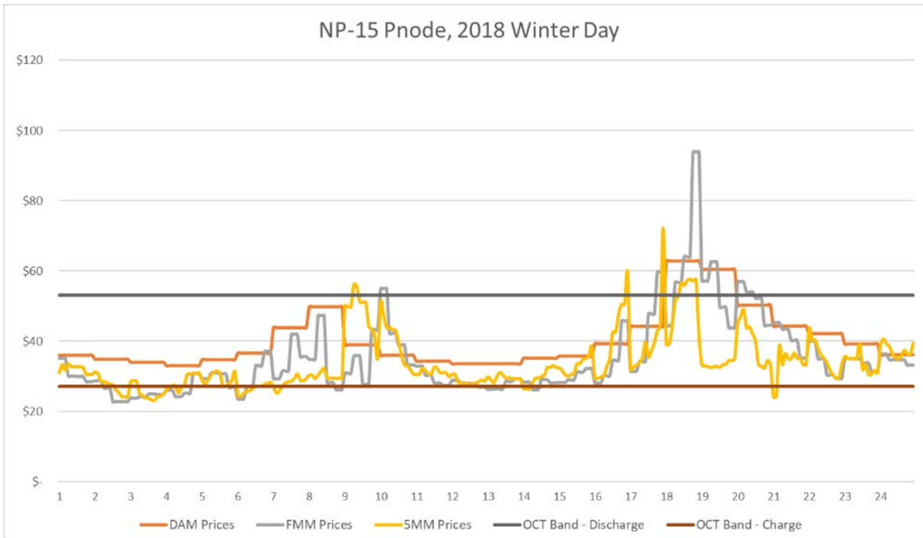

Figure 2: NP-15 Pnode, 2018 Winter Day

In summary, while we think once per day cycling isn't realistic today, we're still very bullish on the economics of storage. We're seeing a number of projects pencil-out cycling only 150-250 times per year. We've also studied scenarios where LMP volatility increases 50%, 75%, 100%, and we still see cycling rates short of once per day – for the same reasons noted above. If your modeling results show otherwise, send us a note and share what you're seeing and where you think we might be wrong. We believe George Box was right when he said, "All models are wrong but some are useful."

Something else we're working on in 2019: Each month this year, we'll be using our eStorm™ model to simulate a fictional 2-MW 4-hour battery on a Bay Area Pnode. We'll share the results and our analysis on our website blog. Why are we doing this? A few reasons. First, the grid is transforming right in front of us and we want to capture those changes in near real-time. With the continued penetration of renewables along with conventional generator retirements, market dynamics are changing rapidly. As market dynamics change, we want to capture and analyze the

[4] $For\ this\ exercise, the\ Charge - Discharge\ Price\ Band = Day's\ Avg\ DAM\ Price\ \pm 1/2 \times \frac{\$26}{MWh} Opportunity\ Cost\ Threshold$

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opportunities created for energy storage. Second, we want to study and show results for different electricity market operating strategies. And third, we want to bring more awareness and visibility to the economic viability of energy storage. We continue to hear that storage is not yet economically viable, and we believe there are a number of cases where it is economically viable. So later this month, look for January results and analysis for this fictional Bay Area battery project.

GridSME Market Portal: Also coming in 2019, GridSME will launch a Market Portal tool that is a quick, easy, and cost effective way to pull CAISO energy price data without the hassle of using hard-to-use OASIS market data sites. Stay tuned. GridSME will make a formal announcement on its website and social media channels when the Market Portal is live.