CRA Insights:
Energy

CRA Charles River Associates

September 2019

Tackling the storage value stack

Wholesale market revenue streams

Forecasting the prevalence of storage in our energy future is no longer novel, but quantifying elements of the storage value stack remains a challenge. In this *Insights* we provide model-based considerations for evaluating the value stack associated with wholesale energy and ancillary services markets.

Background

Energy storage technologies will play an important role in the power system of the future. Grid-scale storage will likely be a necessity to maintain balance between supply and demand, given the ever-growing dependence on emissions-free variable power sources. Declining capital costs and new technologies create a favorable market for storage as do institutional mandates and policies that make storage a priority.

A key challenge to deploying storage resources is identifying and quantifying the “value stack,” the suite of commercial opportunities used to build the business case for storage investments. The elements of the value stack can vary considerably by jurisdiction, and the value of each revenue source can likewise be heavily dependent on local and regional market conditions. A non-exhaustive list of revenue and cost-saving opportunities from the storage value stack includes:

- **Wholesale market value**, including wholesale energy arbitrage, capacity value, ramping capability, and provision of ancillary services like regulation, reserves, and voltage support;
- **Transmission and distribution system value**, including reductions in network charges (via peak reduction), grid congestion relief, and investment deferral; and
- **Distributed generation value**, including household consumption optimization, peak reductions, increased ability to consume self-generated energy, improved power quality, and resilience through blackout and brownout ride-through capability.

A single storage resource may be able to realize several, but not necessarily all, of the above commercial opportunities. Furthermore, as the energy landscape shifts alongside associated regulatory structures, we expect the value stack to be dynamic, both in overall makeup and the relative size of each element. CRA's primary focus in this piece is the evolving wholesale opportunities for storage resource participation in RTO/ISO wholesale markets. FERC Order No. 841 (finalized in February 2018)[1] directed regional grid operators to remove barriers to the participation of electric storage in wholesale markets. By the time compliance is complete, the RTO/ISOs will have lowered the barriers to participation for storage resources in the energy, ancillary services, and capacity markets they operate.

Challenges in quantifying wholesale market value streams

Quantifying wholesale market cash flows is important for any grid-scale investment and is an exercise rife with forecasting and computational challenges. The problem is compounded for storage resources, where complex inter-market optimization issues are more prevalent. Depending on its market offers and operating characteristics, a storage resource may be called upon to switch back and forth between different wholesale services, while being compensated accordingly. Alternatively, the market participant (owner or operator of the resource) may strategically configure the resource's operating parameters to avoid or seek certain opportunities. Furthermore, there is likely to be a growing range of storage technology options, each with its own cost and performance characteristics under regional market participation rules.

To assess the future value of storage resources in this multi-dimensional setting, potential investors and asset owners need a flexible tool to handle the technological and market complexities associated with storage participation in RTO/ISO markets. This level of granularity is not often well addressed by production cost-modeling software, the industry-standard tool for long-term resource valuation. To address the growing need for supplemental storage value analysis, CRA developed the Energy Storage resources OPerations (ESOP) model—a bottom-up decision analysis tool based on multi-period optimization.

ESOP computes optimal storage resource revenues based on participation in energy (day-ahead and real-time) and ancillary services markets (regulation, spinning reserves, and non-spinning reserves). Compared to hourly production cost models, ESOP has the advantage of making more granular settlement interval (i.e., 5-minute) operating decisions along with a more robust representation of technical parameters (e.g., storage capacity, round-trip efficiency, cycling costs, charge and discharge rates, depth of discharge limitations) and constraints imposed by market rules. The model dynamically assesses the optimal markets for participation and how much a storage resource should charge or discharge at any given point in time.

Early insights on energy storage

We have identified three early insights for evaluating future storage opportunities as a result of using the ESOP model in several RTO/ISO markets.

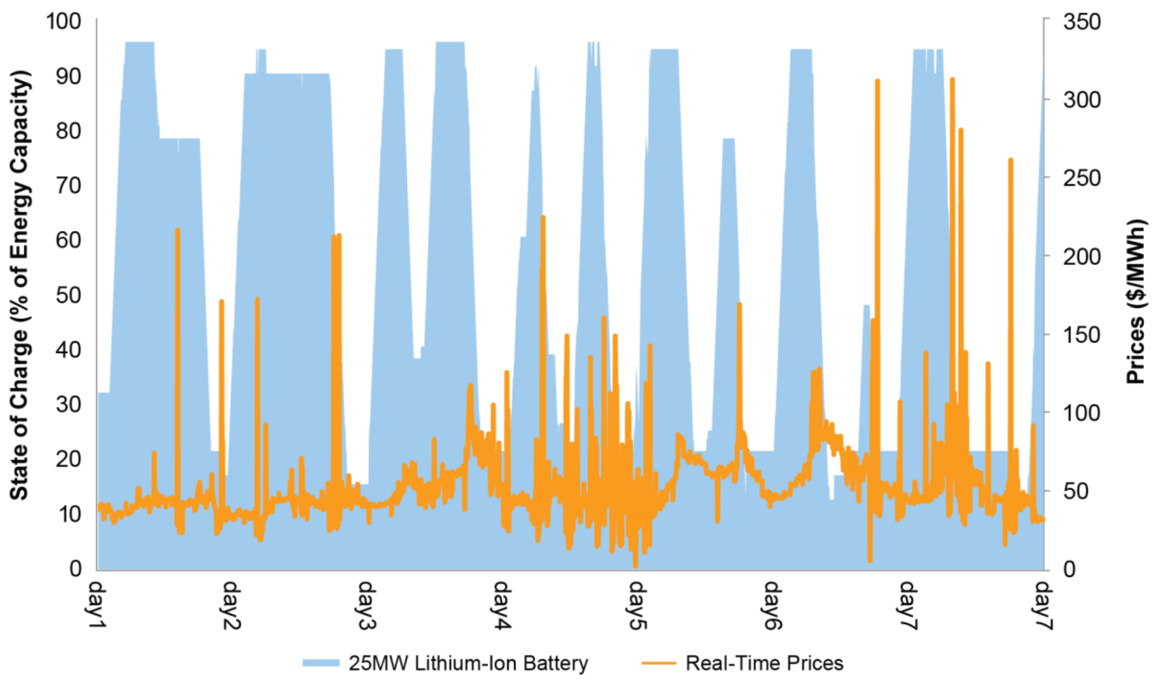
1. **Lithium-ion batteries may find an opportunity to use the synchronized reserves market to reduce degradation costs.** Lithium-ion batteries are highly flexible and responsive, offering potentially high value to markets that reward such characteristics. In the energy markets, we found that substantial value may be available through sequential optimization in the day-ahead and real-time markets. Figure 1 shows a sample ESOP output for a lithium-ion battery, displaying

---

[1] Energy Storage Association, Overview of FERC Order 841, http://energystorage.org/policy/regulatory-policy/overview-ferc-order-841.

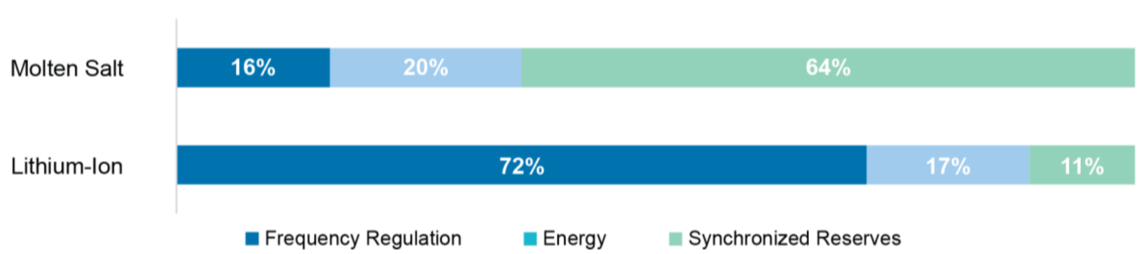
operations of the resource scheduled for day-ahead operations, but with the ability to flexibly respond to real-time price signals within the bounds of realistic operational constraints.

Figure 1: ESOP output: arbitrage optimizing real-time dispatch schedule



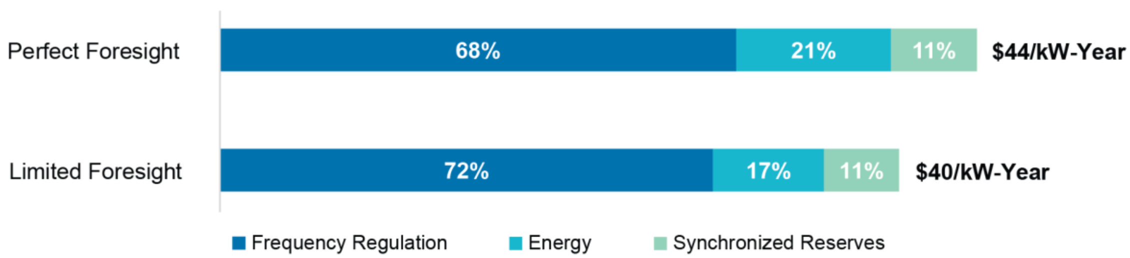
Conventional wisdom suggests that fast-responding technologies like lithium-ion would earn the most revenue in the regulation and real-time energy markets because they can rapidly moderate output or consumption. However, while flexible, lithium-ion batteries have meaningful costs associated with cycling. Because the synchronized reserves market calls for the resource to only occasionally perform, the market provides the opportunity to earn revenue while limiting throughput. Although regulation and energy make up a large portion of the value stack, we found that the market for synchronized reserves consistently provides sizeable value due to the high opportunity costs of throughput (Figure 2). We therefore determined that it is important to account for the role of synchronized reserves in optimizing the storage value stack. More importantly, failing to realistically model certain technological constraints, as is frequently done in storage valuation analysis, may result in underestimating participation in the synchronized reserve market.

Figure 2: Wholesale market revenue streams for lithium-ion and molten salt storage resources in MISO



2. **Technology parameterization informs market participation and expected revenue.** Different storage capabilities can lead to disparate value expectations. Figure 2 also compares the expectations for two storage technologies: a lithium-ion battery and a molten salt storage project. The molten salt resource takes three times longer to charge than to discharge. This asymmetry creates high opportunity costs for charging, as the time to charge one MWh costs approximately three MWhs of revenue earned from discharging. This constrains the slower resource's participation in the frequency regulation market. Once charged, the resource is incentivized to earn revenue while minimizing energy discharge; we found that this can be accomplished by predominantly providing synchronized reserves and discharging only when energy prices are high.
3. **Perfect foresight does not translate into a significant advantage.** In designing ESOP, we experimented with varying levels of predictive capabilities for the model. Under an unrealistic scenario with perfect foresight, we found that for some technology-market pairings, perfect foresight did not significantly increase total revenue. In a recent CRA study on a lithium-ion storage resource in MISO, we found that perfect foresight increased total revenue by less than 10%, as shown in Figure 3.[2] The reason is that certain market products require minimum resource performance commitments, constraining a storage operator's ability to make use of additional information to adjust either offer parameters or its market participation schedule. In short, perfect information is not a significant advantage if a market participant is not allowed to act on that information.

Figure 3: Value stacking strategies under limited and perfect foresight for lithium-ion resource



This observation suggests de-emphasizing the importance of accuracy in short-term load forecasting. Instead, it is more analytically valuable to focus on the physical constraints applied to the storage technology and the market constraints and commitment decisions within which storage resources must operate.[3] That said, as storage technologies advance and resource operations become less constrained, and as market rules promote flexible self-scheduling dispatch strategies, we expect the value of perfect foresight to increase.

Understanding storage value in wholesale markets

A robust view of the wholesale market element of the storage value stack is critically important for valuing future storage resource economics. Storage developers and electric utilities must evaluate

---

2 The analysis assumes that the energy storage resource self-schedules for market participation. RTO dispatch optimization may lead to higher revenue.

3 Examples of market rules include: offer parameters must be submitted 30 minutes before the next operating hour; spinning reserves cannot be offered when providing frequency regulation; once committed to frequency regulation, must stay for one hour.

expected value over their investment horizon and make decisions about project location and technology type. CRA's model can support these analyses by advising on:

- **Expectations for resource operations.** ESOP can help storage owners and operators develop expectations for resource operations under specific offer strategies, and realistic technological and markets constraints. Operating strategies can be optimized over short-, mid-, or long-term value-stacking objectives.
- **Market design choices.** ESOP also helps inform regulators on the potential impacts of market design choices that are driven by the regulatory process. Regulatory intervention regarding storage resource participation rules can facilitate or stymie effective resource participation, and ESOP can help shed light on the effects of alternative approaches. Careful impact analysis of potential rule changes is supportive of robust and non-discriminatory market rule design.
- **R&D efforts.** ESOP's capacity to represent a wide range of storage technologies can help direct R&D efforts of storage technology developers. Simulating the dispatch of new technologies in particular, provides valuable insight on the design of new installations (i.e. address questions such as, "what is the optimal size of a flow battery operating in ERCOT?"). The model also provides direction on technological advancement (e.g. "which performance parameters of lithium-ion batteries should be improved to maximally increase value of the storage resource?").

The authors wish to thank Parag Nathaney for his contributions to this article.

About CRA's Energy Practice

Charles River Associates is a leading global consulting firm that offers strategic, economic, and financial expertise to major corporations and other businesses around the world. CRA's Energy Practice provides services to a wide range of industry clients, including utilities, ISOs, RTOs, large customers, and investors. The Energy Practice has offices in Boston, New York City, Washington, DC, Toronto, and London. Learn more at www.crai.com/energy.

Contacts

Patrick Augustine
Principal
Washington, DC
+1-202-662-3831
paugustine@crai.com

Jordan Kwok
Associate Principal
Washington, DC
+1-202-662-3811
jkwok@crai.com

Wonjun Chang
Senior Associate
Washington, DC
+1-202-662-7883
wchang@crai.com

CRA Charles River Associates