The eStorm™ eBook

Your Guide to GridSME's Energy Storage Operations and Revenue Modeling Tool

Grid Subject Matter Experts, LLC
145 Parkshore Drive, Folsom, CA 95630
(916) 800-4545 | www.gridsme.com
customerservice@gridsme.com

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The Challenge

Battery Energy Storage Systems (BESS) are like no other resource ever seen by wholesale electricity markets. BESS have some characteristics similar to pumped storage hydro (PSH), but there are many fundamental differences. Combined with the difficulty of modeling electricity markets, the result is a considerable amount of uncertainty. But the opportunity in front of storage is apparent. Market volatility is increasing, legacy thermal units are retiring, and the power grid needs more fast-response, high-reliability resources. Storage developers and asset managers are faced with a considerable challenge: estimate BESS's revenue potential – of which a significant portion is expected to come from merchant wholesale market revenues, convince financers of that potential, and then conquer all the other typical project development hurdles. No easy feat.

Introduction

This short eBook introduces the reader to GridSME's Energy Storage Operations and Revenue Modeling (***eStorm™***) tool, our revenue modeling methodology, the model's inputs and outputs, and how it can help you improve your project development odds, reduce capital costs, and improve project performance. The eBook also answers questions commonly asked by our clients and eStorm users so that you have the tools and information you need to successfully bring your BESS projects to commercial operation.

Chapter 1: What is eStorm?

eStorm is a model that uses a market-simulated approach whereby the storage project acts as a resource in wholesale energy and ancillary service markets interval-by-interval – just as it will during actual operations. In eStorm, the storage resource submits bids to the market informed by recent market prices, opportunity cost calculations, and state-of-charge (SOC) information known to the storage resource at the time of bidding and without the benefit of hindsight. In other words, eStorm does not incorporate a hindsight bias, and therefore does not require the model's user to discount eStorm's revenue stream results.

If we had to summarize eStorm's purpose into one sentence, it would be:

Realistically simulate and calculate the operations and market revenue performance of a battery storage technology in a wholesale electricity market.

What Can be Modeled?

eStorm is built to model standalone-storage systems or generation+storage systems (most commonly solar+storage). In the case of generation+storage systems, eStorm can be run assuming one combined resource ID or two separate resource IDs. For a generation+storage project, eStorm is often used to assess different BESS sizes and identify the optimum size and duration given the generation resource's characteristics.

- ✔ Standalone Storage
- ✔ Generation+Storage (1 resource ID)
- ✔ Generation+Storage (2 resource IDs)

What are eStorm's Objectives?

eStorm's objectives are to:

1. Build defensible BESS operating and merchant revenue modeling results…
2. That simulate a repeatable, replicable market strategy and operating profile…
3. And, therefore, don't require a "margin of safety" haircut from financers.
    a. In other words, eStorm improves project IRR's, reduces financing costs, and provides developers, asset managers, and financers clarity on the topic of BESS operations and revenue potential.

To do those things, a storage model should:

1. Simulate the battery interval-by-interval at the five-minute market (5MM) granularity.
2. Avoid the use of hindsight bias for optimization and energy arbitrage.
3. Use recent market data to drive the decision tree when data becomes available (not before).
4. Operate the battery within physical constraints (e.g., SOC min/max).
5. Settle market awards based on the BESS's actual availability, physical operations, and market rules.
6. Quantify realistic settlements from energy & Ancillary Services (A/S) value streams.
7. Test revenue potential given energy price volatility & A/S price assumptions.
8. Factor project costs into opportunity cost and dispatch decisions (e.g., battery costs, capital costs, O&M, project useful life, etc.).

Our Modeling Methodology

eStorm is an emulation of a BESS's market and operating activity as if its decisions and logic were driven by a super-alert, super-focused, and always-on economist, operator, and dispatcher (e.g., a software program). The model follows a repeating logic interval-by-interval every five minutes or 105,120 times per year. At a high-level, the model's logic looks like Figure 1 below.

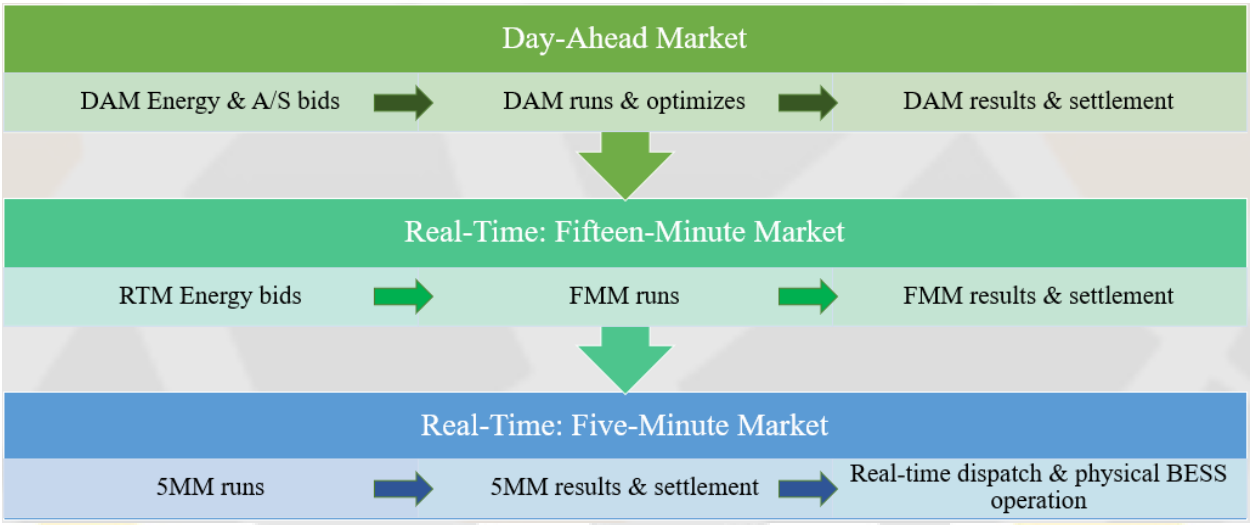

Figure 1: CAISO Market & eStorm™ Modeling Process Flow

Chapter 2: eStorm's Many Uses

Clients use eStorm for many different reasons and in different stages of a BESS project's lifecycle. This chapter discusses those uses.

Planning and Development Phase

During the Planning and Development Phase of a BESS project, eStorm is used to remove uncertainty, avoid low-return investments, wisely allocate capital, and build confidence in your project's success.

1. ***Develop realistic estimates of merchant revenue potential given one or more Pnode LMP and A/S data sets.***

Aside from the project profile info, the key input to eStorm is assumed energy and ancillary service prices. True for any market resource, a BESS's economic performance is highly dependent on market prices. The BESS's behavior and revenue results in eStorm are a function of the assumed energy and A/S price inputs into the model. As illustrated in Figure 1 above, market prices and resource bid prices drive market awards, settlements, and real-time dispatch. Any modeling methodology is incomplete without considering all three. eStorm gives developers the tool needed to compare market price forecast data sets and study the impact of the different data sets on BESS revenue results.

We believe it is wise to model BESS projects using multiple market price forecast data sets. We encourage clients to use multiple extreme case "bookend" data sets and use eStorm to quantify the revenue results under each. This will give developers a high certainty revenue range and help them understand their project's revenue sensitivity to market fluctuations. To forecast energy LMP and A/S price data over the life of a BESS project, GridSME works with the client to create LMP datasets that meet expectations of future price trends. If the client already has forecasted energy LMP and A/S data, those data are easily fed into the eStorm model. Otherwise, GridSME can use eStorm's auxiliary tools to create price forecasts under an array of different assumptions.

2. ***Given merchant revenue potential, solve for the BESS project's resource adequacy revenue need.***

Procured through competitive solicitations, the energy storage resource adequacy (RA) purchase and sale agreement is a common tool used by utilities to meet local reliability needs and encourage the development of BESS projects. This procurement mechanism provides projects with a single contracted revenue stream. But RA bid price is a function of both BESS project cost and all other revenue streams. Similar to eStorm use case #1 above, eStorm is often used to solve for the BESS project's RA revenue need, which becomes the developer's RA bid price in the competitive solicitations.

3. ***Study how sensitive merchant revenue streams are to price fluctuations and changes in price volatility assumptions, including the concentration of revenue in a small number of intervals.***

If there is one thing we know, it's that what don't know what the future holds. Perhaps price volatility goes up. Maybe way up. Or maybe it goes down. Maybe way down. Or it could stay flat. A/S prices could go up. Or they could collapse. No one really knows – some will just be right guessing. The successful will be those that expect and prepare for a range of outcomes. The best way to prepare is to know how different scenarios affect your project's economics. eStorm can provide transparency to see how different price forecast data sets produce different revenue results. In addition, eStorm allows the user to understand how sensitive annual revenue results are to just a few intervals per year. In other words, you'll be able to see what percentage of your annual revenue comes from a small percentage of intervals (e.g., price extremes and the impact of revenue concentration risk).

4. ***Optimize your project size: obtain revenue results for various BESS sizes and durations.***

Using eStorm, clients efficiently analyze operations (e.g., annual cycles) and revenue results given a myriad of different BESS size and duration combinations. For example, a developer looking to optimize its investment's revenue results per kWh of installed capacity can hold all other inputs constant and use eStorm to quickly model each contemplated size-duration combination. Whether a standalone BESS or a BESS paired with a generation resource (e.g., solar PV), use eStorm to zero-in on the optimum BESS size for your project.

5. ***Determine the market and revenue benefit of one vs. two resource IDs for generation+storage projects.***

If your BESS project is co-located with a generation resource, eStorm can be run to look at the combined resource under resource ID or as two resource IDs in the market. eStorm models both approaches and determine which is more lucrative. Use this information to guide your cost-benefit analysis when deciding which option to select.

6. ***Obtain BESS operations and cycle data to present to BESS manufacturers.***

For a BESS operating as a merchant resource in wholesale electricity markets, a considerable amount of uncertainty exists around the battery's cycle behavior. Faced with considerable uncertainty, clients and battery manufacturers use eStorm's results to better understand the likely cycle patterns at both the granular (e.g., five-minute intervals) and high-level (e.g., annual cycle totals). Manufacturers and asset owners also want to know how frequently the BESS might switch from charging to discharging modes.

7. ***Test different market strategies to understand which strategy is most economic.***

A BESS can offer many different energy and A/S products to the market, and some of those products can be combined and "stacked" together. eStorm can run multiple model scenarios side by side, holding all other inputs constant except for market strategy inputs and assumptions. Operate your BESS in regulation and see how the results compare versus a spinning reserve+energy arbitrage approach. Interested to see how a simple full-cycle time-of-day approach compares to price-sensitive economic bidding? Wish to operate the battery depending on seasonal factors? eStorm produces the results needed to answer those questions.

Operations & Asset Management Phase

Once the BESS reaches commercial operation, eStorm is used to dial-in market performance and reduce the merchant risk profile.

1. ***Using recent market data or forecast data, test different market strategies to determine which strategy is likely to be the most lucrative use of the BESS for an upcoming operations period.***

Use recent market data or forecast data for an upcoming operational period (e.g., a month) to test different market strategies and determine the optimum strategy for your BESS project. For instance, eStorm can be used to understand where the BESS might be at risk in the market, test different market bidding strategies, determine which combination of market products is most optimal, and the expected cycle burden.

2. ***Assess and troubleshoot performance: Using recent market data, simulate the BESS's operations in eStorm and compare model results to actual operations data and market settlements.***

During operations, eStorm is used to routinely look back and assess how the BESS performed in the market relative to the model. Actual-versus-model comparisons can be used to troubleshoot operating gaps where the BESS and its operating system might be performing suboptimally. Perform a root-cause analysis by zeroing-in on exact intervals

where actual operations and the model diverge.

3. ***Backcast a recent time period to retrospectively determine the optimum market strategy.***

Every asset owner in every market asks the question, "Can we do better?" Use eStorm to test different market strategies on historical periods and assess where your market strategy can be improved to increase revenue and better optimize BESS operations. Use this information to improve your strategy for current and upcoming periods.

Chapter 3: Inputs & Assumptions

eStorm's flexibility and input fields allow users to model their projects' unique characteristics and account for all known variables. The input fields include the following:

Battery Specs — Power, capacity, and capability inputs

- Charge and discharge Pmin/Pmax
- Capacity and duration
- Minimum and maximum state-of-charge (SOC) range
- Battery degradation assumptions
- Battery re-power assumptions
- Battery rest period between charge/discharge?

Project Profile — Location, generation-coupled, ITC's

- Project location (e.g., GPS coordinates or nearest substation)
- Investment tax credit (ITC) considerations and constraints
- If coupled with generation:
  - Production data for co-located generation (e.g., PVsyst 8760 data)
  - Resource ID's: 1 or 2?
  - Generation+storage POI limit

Market Prices — Market Price Forecast Assumptions

- Energy price volatility, direction, and movement
- Ancillary service price volatility, direction, and movement

Market Strategy — Market products, bid strategy, bid cost assumptions

- Offer Regulation Services?
- Bid cost assumptions
- Bid strategy
- Price-based or time-of-day arbitrage strategy
- DERMS implications? (e.g., charging curtailment during high local load events)

Chapter 4: eStorm's Output & Results

eStorm produces a multitude of different data points – both at the granular (e.g., 5-minute interval) and summary (e.g., annual) levels. These output results are in the form of an Excel file allowing for easy-to-analyze and visualize data sets. The data produced includes:

BESS Operations

- Charge and discharge operations at five-minute interval granularity.
- State-of-charge (SOC) data for all five-minute intervals.
- Cycle counter: know how much your battery cycles for all days and months of the year.
    - Understand how cycle patterns change with changing market dynamics.
- Degradation accounting: eStorm accounts for BESS degradation interval-by-interval.
    - eStorm identifies and reacts to battery repower needs.
    - Customize and model your unique BESS repower strategy – whether it's small augmentations or a major repower, eStorm can model and account for your strategy.
- Key annual operating statistics: annual cycles, battery degradation, average SOC, etc.

Wholesale Market Revenue

- Detailed market revenue results from energy market activity broken down by day-ahead market (DAM), fifteen-minute market (FMM), and five-minute market (5MM).
- Detailed ancillary service revenue broken down by Spinning Reserves, Regulation Up, and Regulation Down for all hours of the year.
- Key annual revenue data:
    - Total net energy arbitrage revenue.
    - Total market settlements broken down by day-ahead market (DAM), fifteen-minute market (FMM), and five-minute market (5MM).
    - Spinning Reserve, Regulation Up, and Regulation Down revenue totals.

Summary

eStorm empowers developers and asset managers throughout the life of BESS projects. eStorm helps determine the optimum size of a storage project, estimate the project's revenue potential, quantify and analyze the project's sensitivity to changes in market prices, asses the effectiveness of a BESS's current market strategy and how to improve it, and much more. Remove uncertainty, reduce risk, generate clarity. Contact us today to learn more about how eStorm can help you be successful!

Thank you for your interest in eStorm. We look forward to helping your energy storage projects succeed.

Matt Barnes
GridSME CFO