California ISO

Energy Storage Enhancements

Issue Paper

April 28, 2021

Market & Infrastructure Policy

Table of Contents

1 Introduction

Grid-scale storage resources are being rapidly deployed onto the California ISO grid to provide replacement capacity for retiring resources and to enable the integration of more renewable resources consistent with the statewide clean energy and climate goals. Energy storage complements intermittent variable energy resources by absorbing excess clean renewable energy and releasing that stored energy when needed to support and sustain grid reliability. Storage is also relied upon in several cases to help meet local capacity resource requirements and there are additional opportunities expected in the future. Given the unique characteristics of energy storage resources compared to traditional energy generation or load resources, new market rules and changes to the ISO's existing energy storage optimization models may be needed to fully integrate these resources into the market, to leverage the flexibility of these resources to maintain grid reliability, and to maximize their use and effectiveness to achieve clean energy goals.

The ISO market models are evolving to address storage requirements. The fourth phase of the energy storage and distributed energy resources (ESDER) initiative, which recently concluded, included development of market power mitigation for storage resources and tools to help scheduling coordinators manage state of charge. Measures targeting storage in the Resource Adequacy Enhancements initiative include counting rules and bidding obligations for storage resources and the introduction of real-time end of hour (EOH) market constraints to ensure day-ahead discharge schedules are feasible in the real-time market. [1]

The storage community expressed concern with existing market rules, optimization algorithms, and settlement processes as applied to the energy storage resources. A principal concern raised by the storage community is a lack of compensation during critical periods when the ISO must retain state of charge on limited energy storage devices, which may preclude their active participation in the real-time markets. The consideration of the charging and discharging cycle of the energy storage is lacking from existing bid-cost-recovery rules, which is designed based on traditional energy generation resources. Another raised concern is related to the multi-interval market optimization as it applies to energy storage resources. The purpose of this initiative is to explore these concerns

---

[1] Resource adequacy enhancements stakeholder initiative: https://stakeholdercenter.caiso.com/StakeholderInitiatives/Resource-adequacy-enhancements.

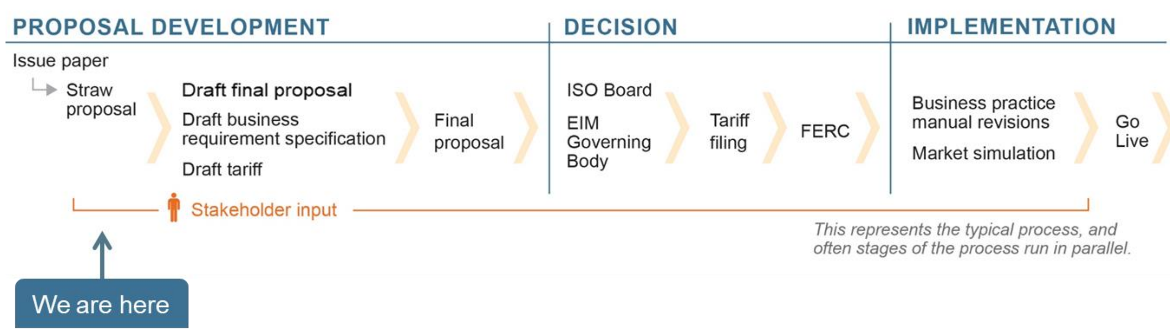
further and develop enhancements to the optimization, dispatch, and settlement of energy storage resources.

2 Stakeholder Process

The ISO is at the "issue paper" stage in the energy storage enhancement (ESE) stakeholder process. Figure 1 below shows the status of the overall energy storage enhancement stakeholder process.

The purpose of the issue paper is to identify and prioritize issues related to the integration, modeling, and participation of energy storage in the ISO's real-time market. After publication of the issue paper and an initial stakeholder call and feedback, the ISO will hold workshops as necessary to engage stakeholders in the policy design process on the prioritized topics. As appropriate, the ISO may organize focused working groups to address issues of a complex nature or those that have cross-jurisdictional concerns as we move through the initiative process. The ISO will publish one or more straw proposal(s) following the issue paper to restate and clarify the prioritized issues based on stakeholder feedback, and propose solutions to the identified issues and concerns.

Figure 1: Stakeholder Process for ESE Stakeholder Initiative



3 Real-time Enhancements for Storage

The ISO introduced the non-generator resource (NGR) model in 2012 to allow for wholesale market participation of energy storage resources. Although the ISO believes that the non-generator resource model effectively integrates energy storage resources today, the increasing number of storage devices participating in the wholesale market warrants investigation of whether further market model enhancements are necessary to ensure that storage is efficiently compensated and the model can accommodate the unique features of storage resources. Stakeholders identified a number of potential enhancements for the ISO to consider to help manage state of charge. While the ISO's day-ahead market optimizes all resources over a 24 hour period, the real-time market has a shorter optimization horizon, which can make it more difficult for to capture periods when it is critical that the storage resources have state of charge for several hours to meet system needs. The goal of this initiative is to explore additional enhancements that could help resource owners improve the control over the state of charge and continue to ensure that the overall market produces optimal and least cost dispatches and efficient market clearing prices.

3.1 Representing Marginal Costs

Efficient energy market dispatch and pricing are rooted in bidding, clearing, and operating resources at their marginal costs. If scheduling coordinators cannot accurately reflect their true resource marginal costs to the ISO market systems revenues may be insufficient to cover costs and the market dispatch may be less efficient. The ISO will explore in this initiative whether the current market bidding functionality allows scheduling coordinators to accurately represent their true marginal costs in the real-time market.

While developing the default energy bid for storage resources in phase four of the energy storage and distributed energy resource initiative, the ISO identified that costs for storage resources are driven by three factors. The first is energy cost, which represents the cost to buy energy from the grid, as well as parasitic loses and round trip efficiencies that prevent the resource from discharging the full amount of energy consumed. The second is opportunity costs. Because energy storage resources are energy-limited, there are opportunity costs associated with failing to charge during the lowest priced hours or failing to discharge during the highest priced hours. The third is cycling costs. These costs are a function of depth of discharge, ambient temperature, current rate, and average state of charge. While the variation in these costs may be minimal if the resource is operating within designed cycle range — which may be one cycle per day — these costs can increase significantly when the battery begins to operate outside these specifications. Current market bidding functionality may not allow batteries to precisely reflect cycling costs.

Influence of Advisory Intervals

The multi-interval optimization (MIO) with look ahead capability is a core elements of ISO market design. The 15-minute market generates optimal dispatch solutions for up to 2 hours into the future. The 5-minute market develops solutions for 65 minutes, or 13 5-minute intervals. These time horizons are critical for issuing startup, shutdown, and dispatch instructions and positioning resources to meet anticipated future system conditions. The ISO real-time market design calls for the settlement of one financially binding interval in the time horizon, leaving remaining intervals as advisory. Occasionally, results for the binding interval – which are sent as dispatch instructions to resources - appear inconsistent with bids because of market conditions during the remaining time horizon. For example, a slow ramping gas resource may be ramped up uneconomically in anticipation of high future loads. Similarly, a storage resource may be charged uneconomically in anticipation of high future prices. Stakeholders suggested reducing the number of advisory intervals considered in the dispatch for storage resources to reduce uneconomic dispatch for these resources.

Spread bidding

Some stakeholders argue that the use of “spread” bidding in real-time may result in suboptimal dispatch, and that the real-time market should only consider discrete prices to charge and discharge rather than the implied spread between these two bids. In investigating this suggestion, the ISO has observed that the real-time market largely dispatches batteries in alignment with discrete bids to charge or discharge. However, the ISO notes that when state of charge limit constraints bind or are close to binding, the market does consider the implied price spread between charge and discharge bids. The ISO is still investigating scenarios when spread bidding in the real-time market creates unintended dispatch instructions.

Bids submission timeline

Today, all resources are required to submit bids 75 minutes prior to the start of the next hour for the real-time market. Stakeholders suggested that the ISO allowing storage resources to update their bid curves less than 75 minutes prior to the start of the hour. As mentioned above, the marginal cost for a storage resource can change dramatically depending on the resource’s current state of charge. For instance, discharging while the resource is at a low state of charge less economic than discharging while at a high state of charge. If scheduling coordinators cannot anticipate a storage resources state of charge during the 75 minutes prior to the start of an hour, bids may not reflect the true marginal cost.

Stakeholders suggested allowing storage resources to update bids intra-hour, noting that ERCOT recently allowed storage resources to update bids every 15 minutes. In reviewing this suggestion, the ISO discovered this would require major overhauls of its market systems that would be time and cost prohibitive. Moreover, the ISO likely would need to offer the functionality to all resources to avoid undue discrimination among technologies. One possible alternative the ISO could consider is to allow storage resources to submit multiple real-time market bid curves that are dependent on state of charge. For instance, allowing scheduling coordinators to submit bid curves that are selected by the optimization depending on current state of charge. One bid set may be applicable when the resource is between 0 and 39% state of charge, another from 40% to 69%, and a third curve from 70% to 100% state of charge. For this solution the real-time market could observe the resource's current state of charge, and apply the relevant bid curve for that market run. Once a bid curve was selected at the start of the market run, it would remain in effect until the start of the next market run.

End of horizon opportunity cost

Storage resources may benefit from a bid parameter that accounts for expected opportunity costs of providing energy later in the day. Although storage resources should include expected opportunity cost in bids. The market surveillance committee suggested that the ISO develop an optional end of horizon opportunity cost bid parameter to represent the opportunity costs of charging or discharging within the real-time market in lieu of holding state of charge for intervals outside the market horizon.[2]

Bid Cost Recovery

Stakeholders suggested the ISO reevaluate bid cost recovery calculations for storage resources. Bid cost recovery ensures resources scheduled in the market recover their costs when the market does not provide sufficient revenues. Bid cost recovery is calculated using settled cost and revenue values from the day-ahead and real-time markets. These values are netted across the day for the

[2] Market Surveillance Committee Opinion on Energy Storage and Distributed Energy Resources, Phase 4, September 4, 2020: http://www.caiso.com/Documents/MSC-OpiniononEnergyStorageandDistributedResourcesPhase4-Sep8_2020.pdf.

real-time market. If short, the resource is compensated. Some stakeholders questioned if this approach is appropriate treatment for storage.

Stakeholders suggested netting costs and revenues for bid cost recovery over the storage charging/discharging cycle, typically 8-9 hours for a four hour duration battery, rather than all 24 hours. Another suggestion is netting all costs to charge resource with the revenue from discharging the resource to ensure the bid spread for the resource is covered.

3.2 Ensuring State of Charge

The ISO's current real-time 5-minute market looks ahead 65 minutes, 13 5-minute intervals, while most of the storage resources take several hours to fully charge. This short time horizon may cause challenges for ensuring that storage resources are charged when needed. It may also create challenges for storage operators that desire to charge during the lowest priced periods and discharged during highest priced periods of the day.[3]

Because storage resources will provide substantial portions of energy to the grid during critical periods of the day, it is important that the ISO reasonably ensure the storage fleet will be charged and able to perform at these times. The following example illustrates how an insufficiently charged storage fleet will result an inability to serve load during a very high stress day of the year.[4]

Example

This very simple example examines the net load profile for the ISO system on August 14, 2020. This was one of the days during the heat storm, but not a day when the ISO administered rotating outages. Net loads on this day exceeded 40,000 MW and there was a steep and prolonged ramping period leading to those peak net loads.

This example makes the assumption of retirement of conventional 24x7 resources and replacement of those resources with storage resources. Specifically, that the system has 40,000 MW of reliable 24x7 capacity to serve load in California with about an additional 2,000 MW of storage capacity.[5]

[3] Nearly all of the storage resources in the fleet today are 4-hour duration batteries. This means that fully charged resources can discharge in 4-hours, and take just over 4 hours to charge due to round-trip efficiencies.

[4] With relatively low penetrations of storage on the system, the ISO will only critically rely on state of charge during the tightest days of the year. As storage penetration increases and as more traditional generation retires, energy from storage (state of charge) will be critical more frequently.

[5] In this paper 24x7 generation references resources that are generally available for most hours of the day and could include natural gas, nuclear, hydro and import resources.

Further, this example assumes that wind and solar generation remain consistent to 2020 levels leaving the net load curve unchanged. Although storage may be frequently charged and discharged in the system on a day-to-day basis, the example system will typically not be reliant on the state of charge from the storage resources. Only on days when the net-load exceeds 40,000 MW would storage be absolutely essential to serving system load. On these days, in the intervals leading to the periods where load exceeds 40,000 MW, having storage resources charged is essential.

Figure 2: RTD Net Loads on 8/14

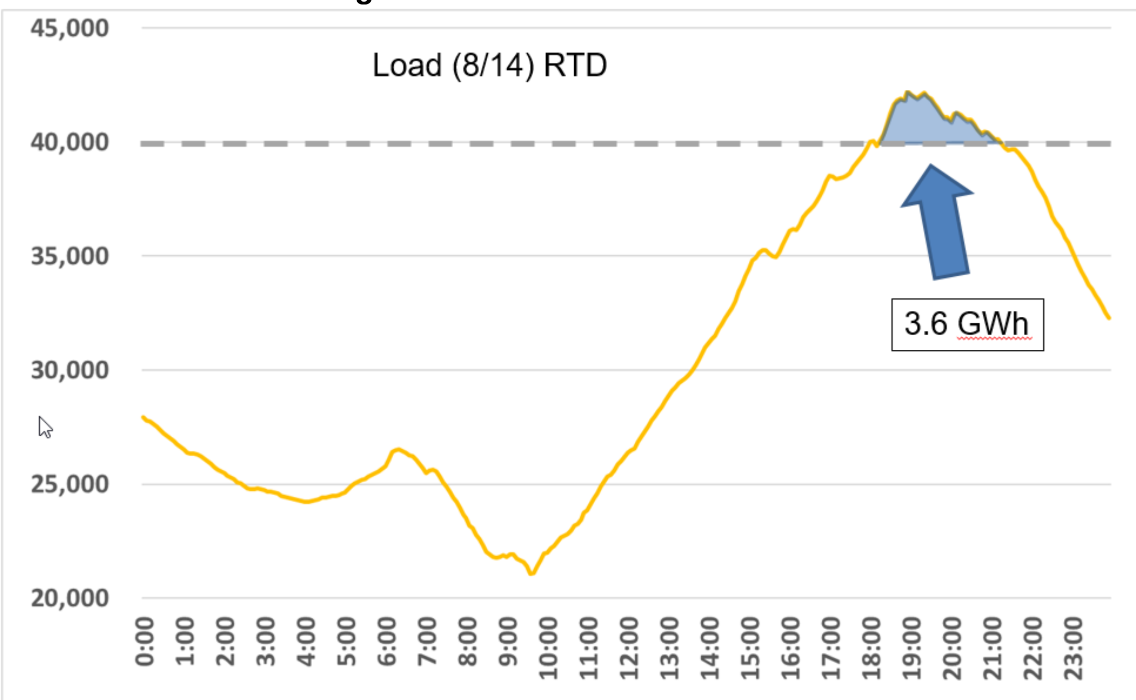


Figure 2 illustrates this example, where the orange line depicts the net load, the grey dashed line illustrates the 40,000 MW of 24x7 available generation, the blue area illustrates the energy required to serve the net-load for all intervals when the net load exceeds 40,000 MW. On this example day the net load peaks at just over 42,000 MW, and the net load remains above 40,000 MW for about 3 and a half hours beginning at about 18:15. Finally, the area between below yellow line and above the grey line, illustrated by the blue shaded area, sums to about 3.6 GWh.

Because of the assumptions in this example, the market cannot serve load during all periods of the net load peak if there is not 3.6 GWh of energy in the battery fleet at 18:15.[6]

In this example, the period where storage resources are critical lasts more than 3 hours. Because the real-time market horizon only includes a single hour, there is no point when the market optimization can fully assess that the market must have 3.6 GWh of state of charge from the battery fleet in order to serve peak net loads. Further, in the event that storage resources are not charged to this level, the real-time market does not observe an interval where there is availability to charge a storage resource, a period when net loads are below 40,000 MW, until about 20:00, hours after the state of charge is required.

Charging the storage fleet to necessary levels cannot be done instantly and will take a significant amount of time. If the storage fleet began completely discharged, was capable of charging and discharging at 2,000 MW, and had an 85% round trip efficiency - on this example day, the storage fleet would need to charge at the maximum possible levels from about 15:15 through 18:15 to achieve the necessary state of charge to serve evening peak loads.[7] This implies that the real-time market would need to consider the timeframe from 15:15 through 21:15 – or a 6 hour period - to calculate the amount of energy required to serve the peak and ensure that storage resources were sufficiently charged to meet that peak from any possible starting state of charge.

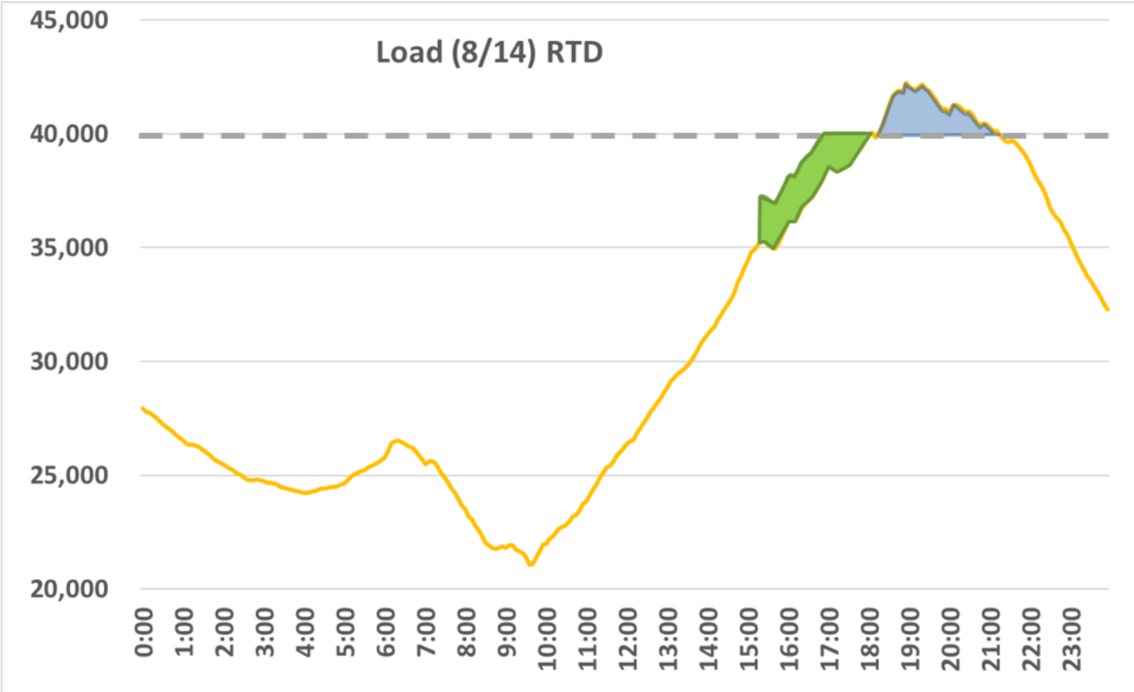
This example is highly contrived and changing the input assumptions changes the needs from our current model. What does not change are the underlying principles that storage will be a required technology type to meet our peak net loads in the future, that the ISO will be relying on storage for multiple hours during the highest net load days, and that the current real-time market does not have a wide enough scope to consider the periods necessary to charge the storage resources sufficiently to ensure availability for the period they are required for use.

---

[6] For simplicity this example ignores RT uncertainty and potential congestion for getting energy from storage to load centers.

[7] Note that these schedules include an infeasible ramp up at 15:15 when all of the batteries in the fleet would suddenly begin charging. In practice, if a significant amount of storage resources are to be charged prior to the evening peak, the ramping requirements must be managed to a feasible level as well.

Figure 3: Charging storage immediately prior to evening peak



This example illustrates three key take always:

1. It is critical for a grid reliant on storage resources to have these resources charged during periods of peak needs;
2. Typical days, with mild or moderate peak net loads, do not require state of charge from storage resources; and
3. As storage penetration gets deeper, and gas and other 24x7 generation sources retire, the need to ensure sufficient state of charge will become greater.

3.2.1 *Potential Policy Direction*

This issue paper is meant to outline concerns that might be addressed through this initiative and stakeholder process. It is not intended to propose the merits of specific solutions at this juncture. Nevertheless, because of the timeframe to develop this policy and new enhancements, the ISO would like to take the opportunity to outline some potential solutions that may be explored through this process as solutions to the challenges outlined above. Three potential solutions are outlined very briefly below and include: 1) extending the look ahead window in the real-time market, 2) developing an energy shift product, and 3) enforcing specific requirements to ensure state of charge in the real-time market.

Expanding the Real-Time Market

- This potential solution is not technologically feasible with the existing available commercial optimization tools

The ISO engaged internally and externally on previous occasions to discuss the possible expansion of the real-time market look out horizon. As noted in the example above, the ISO may require a 6-hour look-ahead window for the narrowest “cycle” to charge and discharge resources. This example does not consider that the optimal time to charge storage, at the lowest priced periods of the day, may be many hours prior to that window. This implies that the best solution for the real-time market may be one that looks out approximately 14 or more hours.

The ISO previously explored expanding the real-time market. Having the real-time market include 6-hours, or more, is technologically not feasible at this time. When the market solves, it optimize over all periods in the solution space, which today includes thirteen 5-minute intervals. Expanding this problem space to 72 intervals (6 hours) causes the solution time to grow exponentially and does not allow for the ISO to arrive at a timely solution to dispatch resources during each five minute interval.

The ISO also explored solutions where time intervals further in the future are less granular. For example, the ISO might consider 3 or 4 5-minute intervals, 3 15-minute intervals, and many hour intervals. Such a solution could allow the ISO to dispatch resources in a specific 5-minute interval considering system information for many hours into the future. The ISO explored such a solution and found there were enormous difficulties in breaking the problems into variable time sizes for advisory periods as formulation complexity is shifted to these boundary intervals switching from one time increment to a different time increments. At this time, the ISO would be unable to implement such a solution.

Scarcity Pricing

Like natural gas resources, storage resources have an economic incentive to participate in the real-time markets to enhance revenue from day-ahead schedules. Unlike gas resources, the decision to provide energy in the real-time market for a storage resource implies a tradeoff between generating now and earning current market revenues or generating later and ensuring day-ahead market revenues. Generating earlier in the day may preclude a storage resource from the ability to generate during periods with a day-ahead schedule, and subject these storage resources to buying back day-ahead awards at real-time prices. These prices could include scarcity prices if there is insufficient supply to meet demand during these periods.

The threat of very high scarcity prices later in the day will temper bids from storage resources so that they will only discharge in the real-time market if prices are sufficiently high if there is a reasonably high probability of scarcity prices later in the day.[8] Infinitely high scarcity prices would dis-incentivize nearly all participation in the real-time market when there was no chance of being able to recharge in time to meet day-ahead awards. Today the ISO has $2,000/MWh scarcity prices, which the market clears at infrequently. These prices do offer some incentive for storage resources to have state of charge available to meet day-ahead schedules. However, there are often prices during the peak ramping periods where storage resources may find it profitable to discharge energy for higher real-time profits despite the potential risk of scarcity pricing later in the day and an inability to deliver energy at that time. Currently, the ISO is not planning to increase scarcity prices to a level sufficient to prevent storage unavailability in the real-time market.

Energy Shift Product

The ISO could develop a new "energy shift" product. This product would be unique where the ISO would procure energy in the day-ahead market from the storage fleet at a specific strike price. That energy would be used to charge specific storage resources during low priced hours in the day, and then would be discharged during specific high net load hours of the day. Storage resources could include lost opportunity costs from not participating in the real-time market into bids for the energy shift product. After a storage resource clears for this product, a requirement would be imposed in the real-time market preventing discharge below the cleared load-shift quantity. The ISO could ensure that sufficient energy shift product is procured to ensure that the storage fleet is sufficiently charged to meet hours when storage resources are critical in the market. The ISO may procure additional energy shift product if it is economic to do so.

Pros

[8] This is true of storage resources making decisions to discharge when there is little or no ability to recharge prior to their day-ahead discharge schedule.

- Relatively straightforward pricing (Marginal Costs + Opportunity Costs)
- Proposal would procure essential storage at least cost time of day

Cons

- New product applicable to variable times could be difficult to implement
- Product will likely not be procured on a 5-minute basis in the real-time market

Biddable Stored Energy Product

Alternatively, the ISO may elect to use day-ahead and real-time market results to infer the total quantity of state of charge that is critically needed to ensure reliability. Then, in both markets, impose a constraint to ensure that state of charge is available across the storage fleet. In real-time, this requirement may be imposed in the early afternoon when prices are lowest, or may be imposed in the hours directly proceeding critical net load hours on the grid. The biddable state of charge product would be bid and priced based on the marginal resource clearing for state of charge.

This potential requirement would specify a total amount of state of charge in MWh. For each real-time interval, the ISO would ensure that sufficient state of charge is available to meet the target. In the event that there is excess capacity, prices would be $0/MWh, otherwise the marginal storage resource providing state of charge would set prices for all storage resources providing state of charge in the real-time market.

Pros

- Relatively simpler to implement
- SOC Product would be maintained in the 5-minute real-time market
- Possible to enforce early in the day or closer to the net load peak

Cons

- *Pricing for this product be challenging*
- *May require local or zonal constraints to ensure deliverability of SOC*

Updates from the Day-Ahead Market

Many potential solutions involve requirements from the residual unit commitment market run in the day-ahead process. Updated information in the real-time market could better inform these requirements. This could include updated forecast values for renewable generation and loads. Previously, the ISO proposed to build a day-ahead reliability tool (DART) to look out multiple hours and help inform procurement. The ISO could use a process with a horizon that looks ahead multiple hours to help inform the requirements to ensure that storage is sufficiently charged.

3.2.2 *Local Needs*

The ISO performs studies in the day-ahead timeframe to ensure local areas can reliably operate during the coming day with the resources that are available (on-line) for dispatch. These studies include reliable operation of the local area even when the single largest or two largest supporting electrical elements in that local area are out of service. Sometimes this means the ISO has to issue start-up instructions to local gas resources so they are available to meet local needs in the event of the loss of one or two of these elements. Today these uneconomic commitments are achieved through the minimum on-line commitment (MOC) tool, which enhances day-ahead market results to include commitments from all gas resources necessary to operate the local systems reliably.

In the future, many local areas may be reliant on storage resources to meet demand. Similar to issues at the system level, it may be critical to charge storage resources to ensure their availability in the local area should a contingency occur. Ideally, any system solution also may be used to accommodate local needs for storage resources. The ISO will need to ensure reliable operations in local areas with any solution that is implemented. A solution may also include updates to the existing minimum on-line commitment tool and/or development of a new tool or constraints in the local areas.

3.3 Variable Charging Rates

Battery storage developers note that charging rates can degrade as resources reach a high state of charge. This can lead to a resource being unable to meet its schedule if the resource is near the top of its state of charge. Where a resource might be able to charge from 0-88% state of charge very quickly (bulk loading), this rate of charging degrades as the resource gets closer to 100% and it may take more intervals to charge the remaining portion of the battery. Currently there is no way to model these state of charge dependent rate changes. Stakeholders have requested that we explore enhancements to the NGR model that would allow market to keep track and optimize the variable charging rates across different states-of-charge of the resource automatically rather than through bid in parameters or outage cards. The ISO requests additional feedback from stakeholders on the pervasiveness of this problem, and whether it is something that could be or is managed on the resource side by oversizing or modifying the Masterfile parameter to reflect a consistent charging rate regardless of the state of charge.

3.4 Exceptional Dispatch

ISO operators can exceptionally dispatch any resource on the grid to ensure reliability. This includes dispatch instructions to provide energy to the grid and dispatch instructions for storage resources to reach a certain state of charge to prepare for peak conditions or other contingencies. If a resource is dispatched for energy delivery to the grid, then the resource will receive compensation at the higher of their bid or the prevailing price for the dispatched (MW) amount. However, if the storage resource is exceptionally dispatched to 0 MW, or to hold state of charge, there is no compensation awarded for that instruction. At the same time, the resource could be missing opportunities to discharge and receive high real-time market prices. Compensating storage for this lost opportunity cost may be appropriate.

Additionally, the ISO may consider creating a new type of exceptional dispatch where the operators can specifically procure state of charge, rather than a target MW amount. Also, the ISO observed instances where the real-time market may discharge a resource in order to make headroom for an exceptional dispatch instruction to charge during the next hour. Allowing operators to explicitly procure state of charge, rather than a target MW, will reduce these outcomes.

4 Next Steps

The ISO requests additional feedback from stakeholders on whether prior comments and suggested for policy changes stem from different issues outlined in this paper. The ISO asks stakeholders to identify current and additional issues as feedback to this issue paper. The ISO will begin tackling solutions to these problems in the first straw proposal.

The priority to effectively manage the transforming grid and stakeholder requests for better control over state of charge and additional compensation mechanisms for storage resources is important. The ISO will host a stakeholder call on May 5, 2021 to review the issue paper, and encourages all stakeholders to submit comments on the issue paper with additional issues that should be considered as part of this policy. The ISO requests stakeholders present data, if available, to help inform any of the identified issues detailed above or any new issues submitted through comments.