Energy Storage and Distributed Energy Resources Phase 4

Second Revised Straw Proposal

February 24, 2020

Prepared by

Lauren Carr

Gabe Murtaugh

Jill Powers

Table of Contents

1 Introduction

The focus of the California Independent System Operator's (CAISO) energy storage and distributed energy resources (ESDER) initiative is to lower barriers and enhance the ability of these resources to participate in the CAISO's market.[1] The number and diversity of these resources continue to grow and represent an important part of the future grid.

The ESDER initiative is an omnibus initiative covering several related but distinct topics. This paper presents the elements included in the fourth phase of the ESDER initiative. It describes the CAISO's efforts to continuously improve and enhance its interaction and participation models for both storage and distributed energy resources in the CAISO's market.

ESDER 4 Second Revised Straw proposal addresses the following topics:

1. State-of-charge biddable parameter for the non-generator resource model;
2. Streamlining interconnection agreements for non-generator resource participants;
3. Applying market power mitigation to energy storage resources;
4. Maximum daily run time parameter for demand response; and
5. Vetting qualification and operational processes for variable-output demand response resources

2 State-of-Charge Parameter

The CAISO introduced the non-generator resource model in 2012 to enable wholesale market participation of energy storage resources. Although the CAISO believes the non-generator resource model effectively integrates storage resources today, the increasing number of storage devices participating in the wholesale market warrants further investigation of the model to ensure the CAISO is using these unique resources optimally to meet the reliability needs of the grid.

Stakeholders have expressed a desire to more effectively manage their non-generator resources state-of-charge in the real-time market in order to meet day-ahead schedules or other obligations that may be present outside of the real-time market optimization window later in the day. Stakeholders recognize that while the day-ahead market optimizes the resource across the entire operating day, when participating in the real-time market the resource will receive dispatches based on system supply/demand condition and prices available a shorter optimization horizon. This could result in a deviation of the non-generator resources state-of-charge derived to meet their day-ahead schedules. For instance, based on the resource's bids, the real-time market may find that it is most economic, over the short-term, to leave a storage resource fully

[1] DERs are those resources on the distribution system on either the utility side or the customer side of the end-use customer meter, including rooftop solar, energy storage, plug-in electric vehicles, and demand response.

discharged early in the day making it incapable of meeting its obligation to deliver on a day-ahead award later in the day.

Currently, self-schedules can be utilized to help manage the state-of-charge to meet these obligations, however, effective use of them to achieve a desired state-of-charge is difficult due to lag between market execution and bid submission deadlines. Additionally, use of self-schedules limits the CAISO's ability to flexibly dispatch the resource throughout the operating hour it self-schedules. A more effective means for management of the non-generator resources state-of-charge in real-time while allowing for greater flexibility of its use is needed.

Proposal

The CAISO proposes allowing scheduling coordinators to submit end-of-hour state-of-charge parameters for non-generator resources in the real-time market to manage the use of their non-generator resources throughout the day.[2] Scheduling coordinators will be able to submit an end-of-hour state-of-charge value with their bids in the real-time market. In addition, the scheduling coordinator can represent the end-of-hour state-of-charge parameter as a minimum and maximum range.

Scheduling coordinators are able to update their real-time bids at any point after the day-ahead market and up until the relevant real-time market closes. The market will use the submitted end-of-hour state-of-charge when the real-time market's optimization horizon reaches the end of the respective hour. The CAISO will not extend the end-of-hour state-of-charge bid into the following day-head market. A scheduling coordinator will be responsible for submitting an initial state-of-charge that ensures feasible market scheduling of the resource in that following day-ahead market.[3] The scheduling coordinator will submit an end-of-hour state-of-charge to reflect a minimum and maximum range. If the scheduling coordinator desires a target state-of-charge, then the minimum and maximum state-of-charge values should be set the same.

The end-of-hour state-of-charge bid parameter will work in conjunction with the existing MasterFile and SIBR minimum and maximum energy limits, and NGR bid-in parameters for upper and lower energy charge limits. However, instead of ensuring that resources receive an economic dispatch within the MasterFile or bid-in energy limits, the proposal will allow the market to dispatch non-generator resources economically or uneconomically to achieve the scheduling coordinator's preferred hourly end-of-hour state-of-charge when offered to the CAISO. The elected end-of-hour state-of-charge parameter takes precedence over economic outcomes in the market optimization.

2.1 End-Of-Hour State-Of-Charge Bid Parameter

The real-time market will respect all resource constraints when determining a non-generator resource's optimal dispatch. The hourly end-of-hour state-of-charge

[2] End-of-hour state-of-charge parameter will not apply to non-generator resources electing to provide regulation using the regulation energy management (REM) functionality.

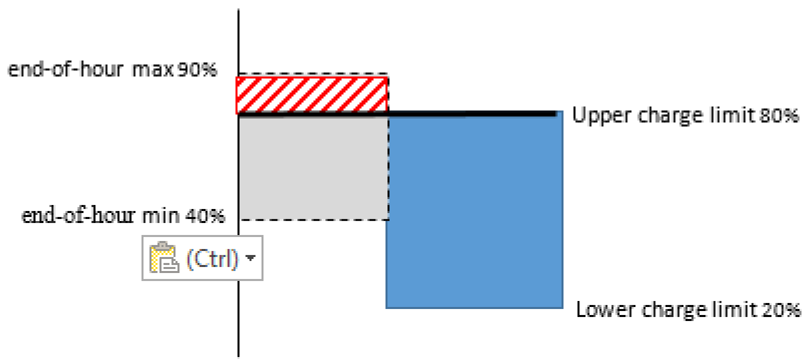
[3] Day ahead market bids are submitted 14 hours before the start of the day and real-time market bids for the last hour of the day must be submitted 2 hours and 15 minutes before.

parameter adds additional constraints to the market optimization. The real-time market will respect modeled resource constraints, including the end-of-hour state-of-charge.

Upper and lower state-of-charge constrained

The real-time market will always respect a non-generator resource's upper and lower state-of-charge values. Consequently, the market optimization will ignore hourly end-of-hour state-of-charge values if they fall outside the resource's defined or bid-in upper and lower state-of-charge values. For instance, as shown in Figure 1, if a scheduling coordinator submits an end-of-hour state-of-charge of 90% for a resource with an upper state-of-charge maximum of 80%, the market will consider the submitted end-of-hour state-of-charge to be 80%, not 90%. A 90% end-of-hour state-of-charge would be infeasible based on the resource's modeled parameter.

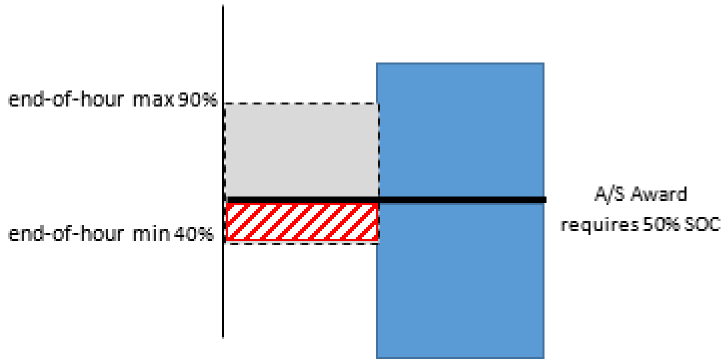
Figure 1: End-of- hour state-of-charge constrained by upper and lower charge limits



Ancillary service award constrained

The market will respect ancillary services awards when a scheduling coordinator provides end-of-hour state-of-charge values that are not feasible. The market will maintain a state-of-charge if the resource is providing ancillary services such that the resource can provide the full awarded MW amount over a 30-minute period. As illustrated in Figure 2 below, if a scheduling coordinator were to submit an end-of-hour state-of-charge of 40%, but the resource's ancillary service awards require a 50% state-of-charge, to ensure the ancillary service's award can be met, the market will adhere to the 50% state-of-charge.

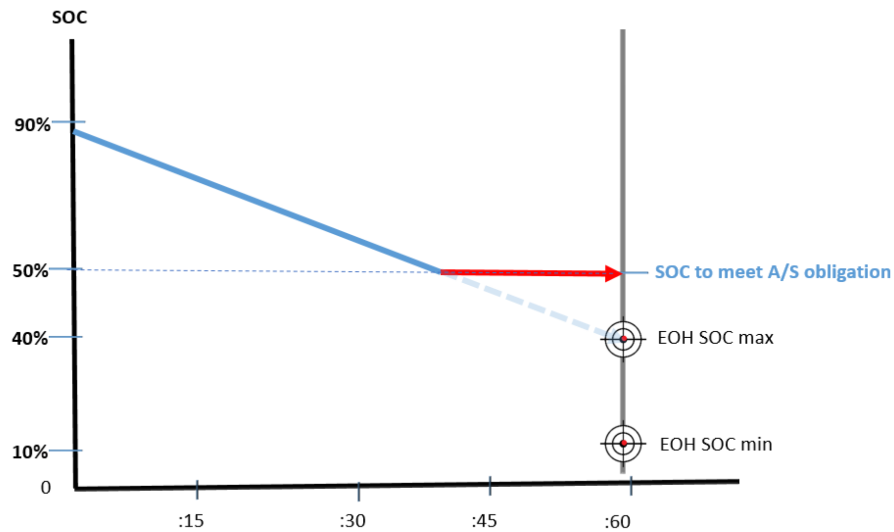
Figure 2: End-of-hour state-of-charge constrained by ancillary service award



When a non-generator resource is providing energy simultaneously with ancillary services, the market cannot guarantee to meet a targeted end-of-hour state-of-charge range. For resources providing regulation services, this is due to an independent management of awarded regulation and energy services between the Automatic Generation Control (AGC) system and the real time energy market. This is also true for resources awarded spin and non-spin capacity as, depending on system needs, the capacity could be converted to energy until the end of the hour impacting the resources trajectory to a state-of-charge position. While the market will attempt to move the resource to the targeted end-of-hour state-of-charge it could fluctuate upward or downward in proportion to the ancillary services awarded. Therefore, in hours where the resource receives simultaneous ancillary service and energy awards, there is no guarantee that the resources end-of-hour state-of-charge will be met. As illustrated in Figure 3 below, due to the impact of an Ancillary Service award requiring a 50% state-of-charge in an hour for which an end-of-hour state-of-charge range was submitted, while the market may track to the minimum 10% or maximum 40% it would be constrained by what was needed to meet the ancillary service obligation until the end-of-hour.

Some stakeholder comments suggested that an end-of-hour state-of-charge bid not be allowed in hours the resource has received a day-ahead ancillary service award. At this time, the CAISO is not proposing to restrict the use of an end-of-hour state-of-charge continuing to allow it as an option with recognition of the known impact of a simultaneous ancillary service award.

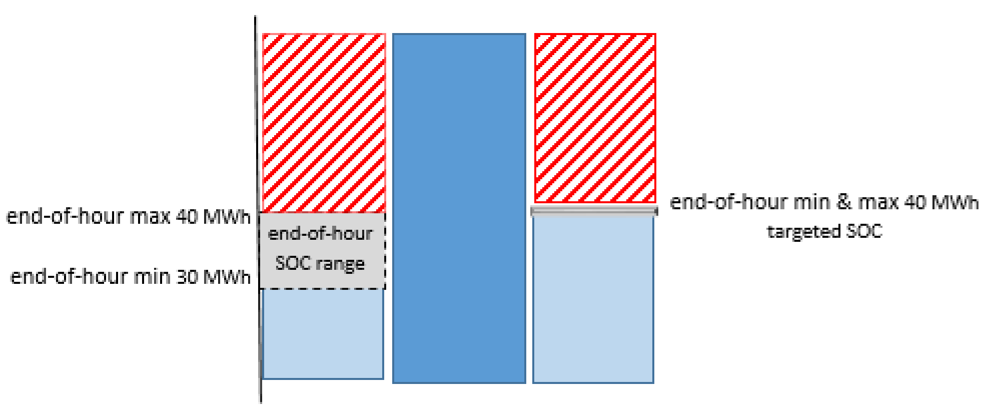
Figure 3: Impact of Ancillary Service award to an end-of-hour state-of-charge



Range in state-of-charge bid

The scheduling coordinator will submit the end-of-hour state-of-charge parameter as a range. Meaning, the state-of-charge in MWh will represent a minimum and maximum value the market will respect. For example, in Figure 4, if a scheduling coordinator wants to meet a specific state-of-charge of 40 MWh, it will submit a minimum value of 40MWh and maximum value of 40MWh. The market will optimize the non-generator resource to meet the targeted value. If a scheduling coordinator needs a resource to have a minimum state-of-charge of 30 MWh regardless of market prices and a desire to charge up to 40 MWh if it is economic, the bid will represent a range of 30-40 MWh. Dispatches up to the minimum value of 30 MWh may or may not be economic for the resource. If market prices are economic for the resource in the 30-40 MWh range, the market will dispatch the non-generator resource up to a value within the range of 30-40 MWh.

Figure 4: End-of-hour state-of-charge bid range



The CAISO will publish non-generator resource hourly end-of hour state-of-charge bid information on OASIS along with all other bid information in accordance with existing timelines.

Market application of the end-of-hour state-of-charge bid

Real-time bidding parameters are submitted to the market 75 minutes prior to the start of the hour. This timeframe will apply to resources submitting values for the end-of-hour state-of-charge minimum and maximum parameters. Once received these values will be used to inform dispatch instructions for resources in the successive 15-minute market (RTPD) interval and the corresponding 5-minute interval.

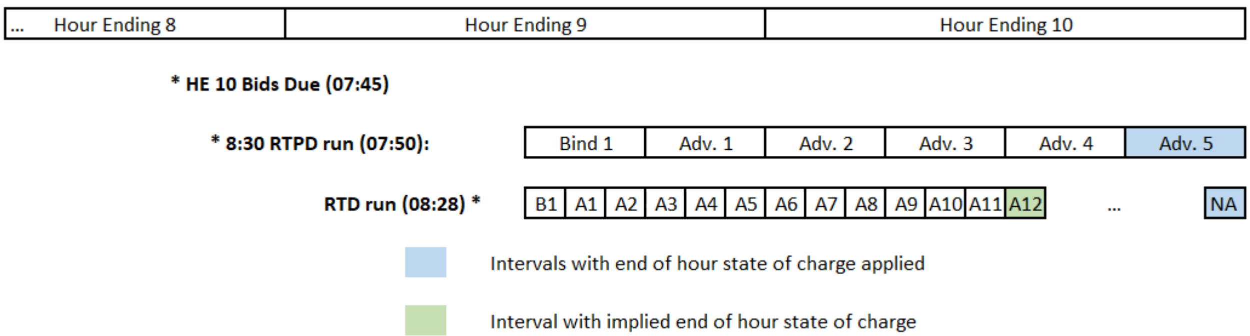
For example, a resource may submit a minimum state of charge parameter applicable for hour ending 10. Bids for hour ending 10 are due at 07:45, or 75 minutes prior to the start of the hour at 09:00. At 07:50 the binding market run for the 15-minute market (RTPD) begins for the 08:30 interval, which generates binding market instructions for the first interval, from 08:30-08:45, and advisory instructions for the 5 successive intervals from 08:45-10:00. Since this is the first market run to observe the end-of-hour state-of-charge bid submitted, effective for end-of-hour 10, the value will be respected in this market run, for each of the advisory and the binding intervals.

A resource with a 45% state-of-charge at 08:30 and an end-of-hour state-of-charge bid of 80% by the end of HE10 will have schedules to charge in the binding and advisory intervals, beginning with the 15-minute market (RTPD) run for the 08:30 binding interval, assuming that to meet the state of charge of at least 80% by HE 10 all intervals of charging are required based on its resource characteristics.

The 5-minute (RTD) market is different. This market runs 7.5 minutes prior to the start of a specific 5-minute interval and looks out up to 65 minutes, which represents 1 binding and 12 advisory 5-minute intervals. At 08:07:30 the 5-minute (RTD) market begins solving the binding interval from 08:15 to 08:20. This is the first point in time the 5-minute (RTD) market will have information about the end-of-hour state-of-charge bid. However the 5-minute (RTD) market will not take that end-of-hour state of charge bid into consideration until the last interval of the 5-minute (RTD) run time horizon reaches the end of the hour, which is the run containing the binding interval 09:05-09:10. Because the 5-minute (RTD) does not see the constraint until 09:05, but FMM sees the constraint at 8:30, there may be a sub-optimal situation where the 5-minute (RTD) market could undo what was planned in the 15-minute market (RTPD), by not dispatching to charge the resource until it is too late to meet the end-of-hour state-of-charge target. CAISO proposes to align visibility of the end-of hour state-of-charge bid constraint to the same binding intervals for both the 5-minute (RTD) and 15-minute real-time (RTPD) markets. Specifically, the CAISO will apply an implied end of hour constraint at the end of the time horizon for 5-minute (RTD) runs for binding intervals starting 8:30 to 09:00. This end of horizon constraint will be set to the end of hour constraint, adjusted for the resources full charging capability between the end of horizon and end of hour.

For example, if a resource is capable of storing 100 MWh of energy and is capable of either charging or discharging at 1 MW per 5-minute interval (12 MW per hour) and has an end-of-hour minimum state-of-charge of 80 MWh for hour ending 10, then the market software would imply a 79 MWh requirement for the 11th interval of the hour (09:50 to 09:54), if the market does not consider the final interval of hour ending 10 as an advisory or binding interval. Similarly, the 10th interval of the hour will have a 78 MWh requirement, the 9th interval will have a 77 MWh requirement etc., which are imposed when each of these intervals is considered as the final advisory interval in the current 5-minute market run. At this time, the CAISO is considering other approaches to how the end of horizon constraint may be calculated to ensure the most refined method is developed for the final proposal.

Figure 5: RT Market Application for the End-of-hour state-of-charge Parameters



<u>Non-generator resource Bid-Cost Recovery rule changes</u>

The CAISO will exclude a non-generator resource's bid cost recovery settlement in hours when an end-of-hour state-of-charge bid parameter or self-schedule has the potential to create an uneconomic dispatch. If the CAISO must dispatch a resource uneconomically to meet a non-generator resource's optional end-of-hour state-of-charge bid, or to maintain a state-of-charge necessary to meet a self-schedule, it is doing so to meet the scheduling coordinator's strict requirement regardless of market prices. The CAISO believes, and stakeholder comments support, that the resource should bear the associated costs of this movement rather than require the CAISO to uplift the costs to aggregate demand.

Therefore, a non-generator resource will be ineligible to receive bid-cost recovery for an hour with an end-of-hour state-of-charge bid. The CAISO is also proposing to additionally include ineligibility of bid-cost recovery for the hour preceding the hour in which an end-of-hour state-of-charge is bid. This additional hour of ineligibility is in response to comments received on the revised straw proposal from the Department of Market Monitoring. The comments identified concern that the impact of the target end-of-hour state-of-charge constraint may extend beyond the adjacent hour.[4] The CAISO in its development of the optional end-of-hour state-of-charge bid parameter recognized that today non-generator resources can self-schedule and receive bid cost recovery

---

[4] CAISO DMM's comments to ESDER 4 Revised Straw Proposal (page 7) http://www.caiso.com/InitiativeDocuments/DMMComments-EnergyStorage-DistributedEnergyResourcesPhase4-RevisedStrawProposal.pdf

even though the market must optimize around the self-schedules. Therefore, a self-scheduled non-generator resource will also be ineligible for bid-cost recovery in the hour preceding the self-scheduled hour.

2.2 End-Of-Day State-of-Charge Parameter

Some stakeholders commented that they would like the ability to bid into the market at "true spread bids." The CAISO understands this as a request that storage resources are neither required to be net buyers nor net sellers of energy, but rather they be energy neutral in the 24-hour day-ahead market. In other words, every MW of energy that the resource is buying in the day-ahead market is also being sold, and that the prices for those transactions all occur at spreads greater than the "spread" being bid into the day-ahead market.

For example, a storage resource bids to charge at $20/MWh and to discharge at $50/MWh. The resource might either be 1) discharged during more hours than is scheduled to charge (and this difference could be significant), or 2) may charge for more energy than the resource is scheduled to discharge.

Based on discussions with stakeholders, both scenarios are probable and potentially problematic. If prices are particularly low (i.e. lots of hours with prices below $20/MWh) then the storage resource would be scheduled to charge during the cheapest hours of the day, and may not be scheduled to discharge; or prices could be high (i.e. lots of hours with prices greater than $50/MWh) and the resource could be scheduled to discharge for the highest priced hours, but not scheduled to charge.

In this version of the proposal, the ISO considers an option that storage resources have access to an end-of-day state-of-charge parameter. The CAISO is seeking stakeholder feedback on this proposal and additional feedback to pursue this proposal or not. If adopted, this parameter would be applicable in the day-ahead market and could be set by market participants at any value between 0% and 10% state-of-charge. This allows the non-generator resource to enjoy "true spread bidding" in the day-ahead market, with a schedule that would likely disrupt actual day-ahead schedules very little. The ISO is not inclined to substantially widen the allowable values for the end-of-day state-of-charge parameters because of concerns that higher values of the parameter might significantly perturb dispatch instructions that a similar unconstrained storage resource might receive, which likely indicate significant losses of efficiency.

This parameter, paired with the expected start of day state-of-charge, which is provided to the CAISO as an input parameter prior to running the day-ahead market, should ensure that resources are achieving a "true spread bid." This should allow storage resources to ensure that the energy purchased (less losses) equals the amount of energy sold and that all energy bought and sold in the market will reflect the price spread for bids between the charging and discharging range for the storage resource.

Modeling

The ISO conducted analyses recently to better understand the optimal operations of battery storage resources in the day-ahead market using market simulation models. The model simulations predict market clearing prices and determine the charging and discharging schedules of storage resources, subject to an end-of-day minimum state-of-charge requirement.[5] Generally, storage resources charge during the peak solar hours of the day and discharge during the evening net-peak hours of the day, as indicated in Figure 6. This is consistent with the lowest and highest priced intervals of the day, in the day-ahead market today.

The model used for this analysis was constructed based on the CPUC 2019-2020 integrated resource plan (IRP) proposed reference system portfolio for 2030, which includes about 15,000 MW of battery storage resources, mostly comprised of 4 hours batteries and with 85% round-trip efficiency.[6] The simulation optimizes two days of operations, on the peak load day, simultaneously and keeps the results of the first only, given hypothetical schedules for the following day. Four scenarios were simulated, each with differing end-of-day minimum state-of-charge requirements. These requirements were set at 5%, 20%, 50% and 75% of maximum energy storage for each resource. The results of this exercise illustrate how the end-of-day minimum state-of-charge impacts the operation of storage resources.

Figure 6 shows the average end-of-hour state-of-charge for the entire storage fleet on September 3, 2030, the annual peak load day. In each scenario the minimum end-of-day state-of-charge value binds because all resources, including the full energy capacity of storage, are needed to provide meet peak net-load. Storage resources have the least amount of charge in hour 22, after beginning to discharge at about hour 18. Further, each of the resources begins to recharge in hours 23 and 24 to meet end-of-day minimum state-of-charge requirements set in each of the scenarios. It is also worth noting that outside of the hours that are directly impacted by the end-of-day minimum state-of-charge parameter, each resource performs almost identically. This is indicated by the similar patterns for each of the different resources between hours 6 through 17.

[5] This is different than the specific state of charge parameter that is detailed above, and may eventually be proposed for implementation.
[6] Proposed Reference System Plans, California Public Utilities Commission: https://www.cpuc.ca.gov/General.aspx?id=6442463190.

Figure 6: Average End-of-Hour State-of-Charge for the Battery Storage Fleet

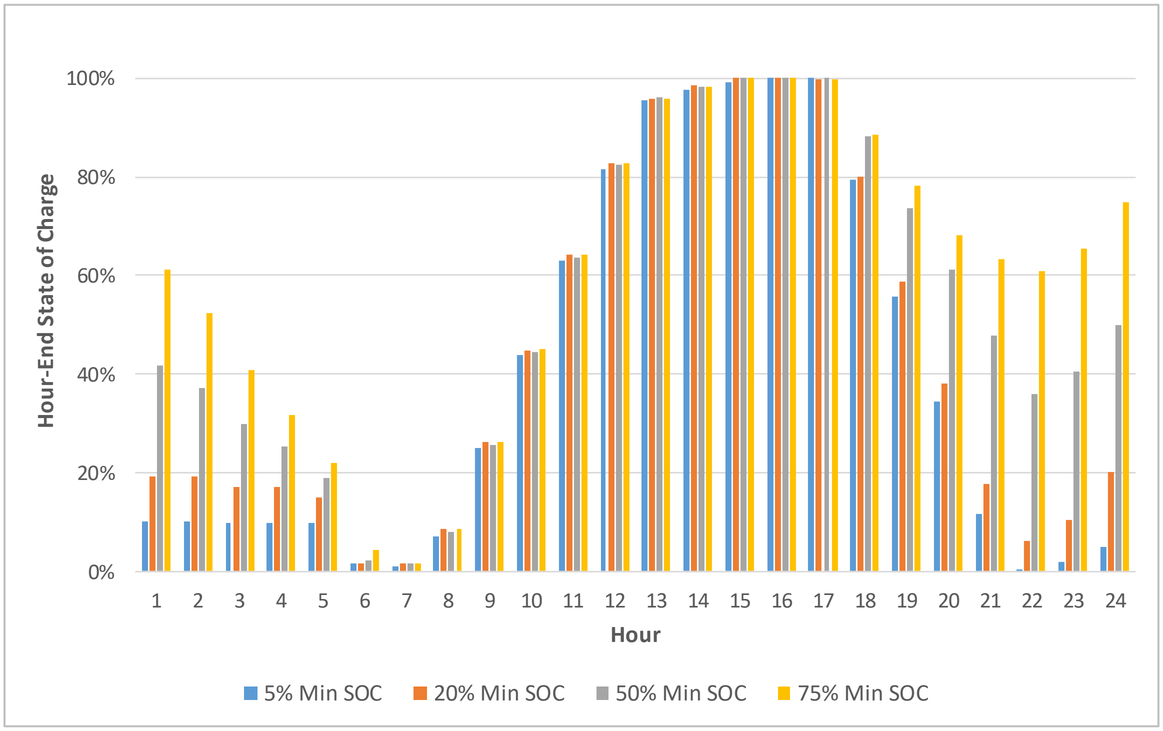
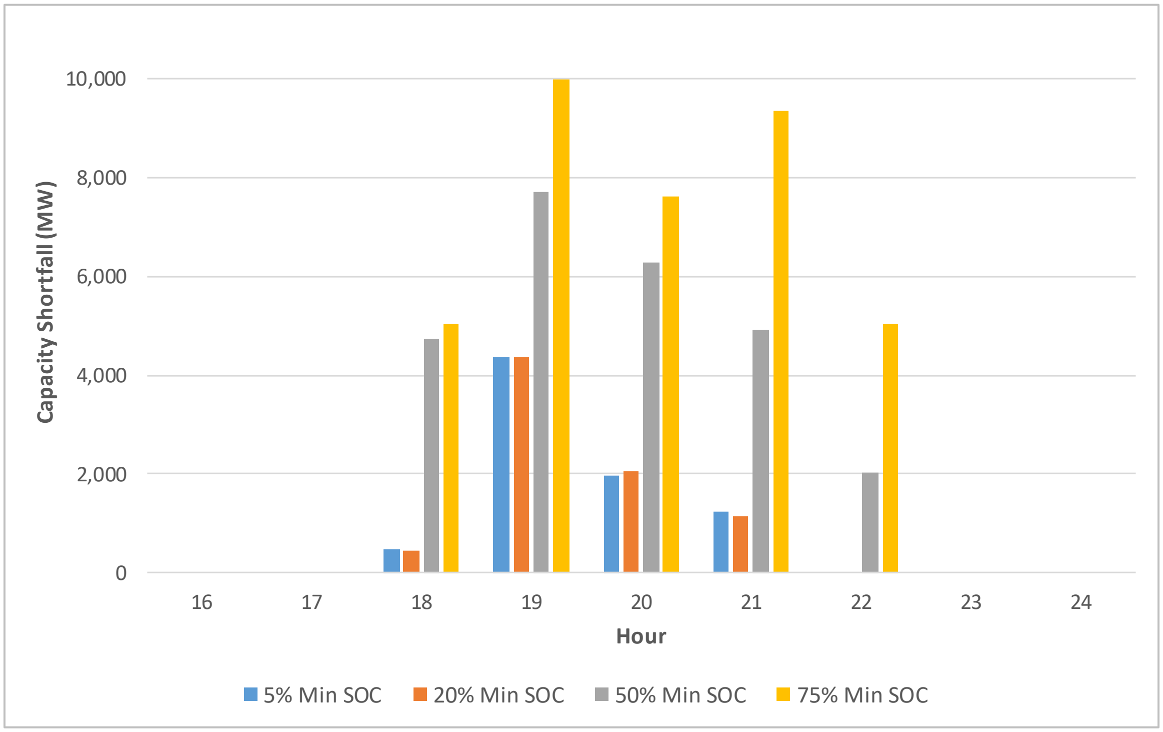


Figure 7 shows simulated capacity shortfalls for each of the four scenarios. Initially the model is set only with the system reference portfolio, and that mix of resources shows that there is insufficient capacity to meet loads.

Figure 7 also shows that the capacity shortfalls increase drastically as larger end-of-day minimum state-of-charge requirements are enforced.

The most efficient outcome for the grid is if storage resources have no minimum requirements placed on them during any interval. Setting a high end-of-day minimum state-of-charge significantly reduces the energy output of battery and causes system reliability issues, when examining system conditions on the peak load day. Additional analysis may be required to determine ranges of end-of-day state- of-charge that would be the least impactful during other times of the year.

Figure 7: Simulated Capacity Shortfalls with Minimum End-of-Day State-of-Charge Applied



3 Non-Generator Resource Participation Agreements

Non-generator resources currently must execute the participating generator agreement and participating load agreement to participate in the CAISO markets. To reduce administrative burden and improve efficiency, the CAISO is proposing that non-generator resources will participate in the CAISO market solely under the participating generator agreement. Only non-generator resources acting as dispatchable demand response will execute the participating load agreement (and not a participating generator agreement). These modifications will not affect the current treatment of non-generator resource and dispatchable demand response in any CAISO market systems. Non-generator resources that have already executed participating generator agreements and participating load agreements will not be required to execute new agreements or terminate existing agreements.

4 Market Power Mitigation for Storage Resources

To ensure that wholesale prices are just and reasonable, the CAISO and other organized markets have mitigation measures to minimize the exercise of market power and non-competitive outcomes.[7] The CAISO employs a tool called local market power mitigation (LMPM), which replaces market bids with marginal cost based default energy

[7] For example, a generator may have the ability to exercise market power when supplying energy within a transmission-constrained area if it is a pivotal supplier.

bids (DEBs) when it detects potential market power. The local market power mitigation tool helps to ensure that market prices are economic in uncompetitive situations.

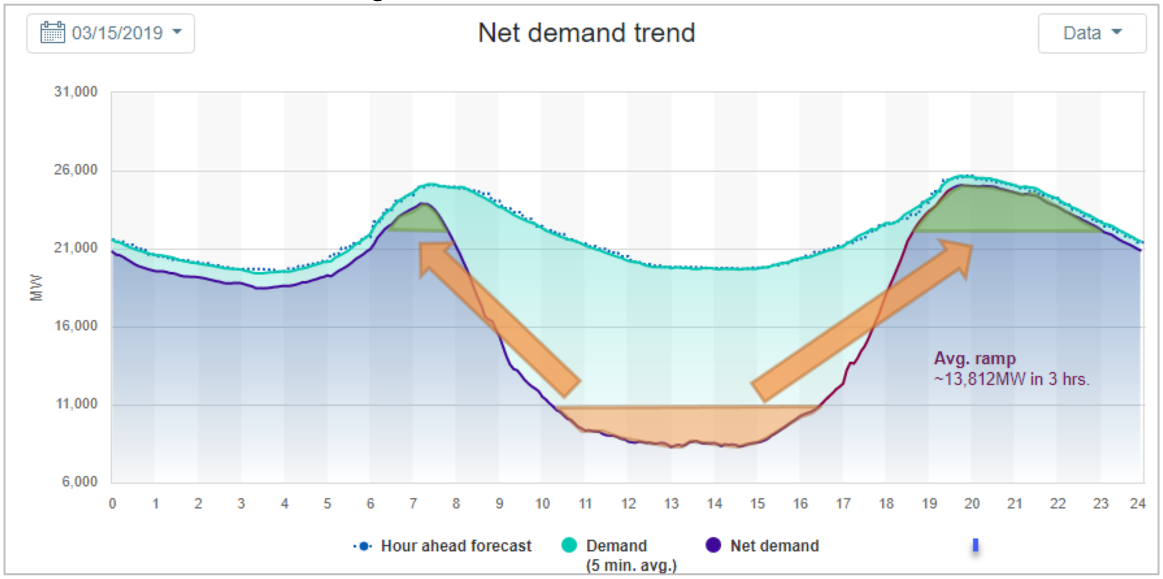
Today, there are about 150 MWs of grid-connected storage resources installed on the system; none is currently subject to market power mitigation. This number does not include behind the meter storage resources installed in households or businesses. However, there are over 48,000 MW of storage generation in the CAISO interconnection queue, some of which could potentially be developed and deployed on the system within the next few years. [8] The CAISO believes that it is important and not too early to begin vetting and developing mitigation measures to manage potential market power of energy storage resources.

Storage resources can be versatile and have various opportunities to earn potential revenues in the CAISO day-ahead and real-time market. Some of these opportunities include arbitraging energy market prices and potentially moving large amounts of energy from low priced periods to high priced periods in the day to help with renewable integration. These resources are also generally flexible and have fast ramping capabilities to offer ancillary services to the market. Balancing potential revenue streams, in addition to potential fixed payments through the resource adequacy framework, can be challenging for certain storage resource types given their cost structure.

Prices in the day-ahead and the real-time markets generally follow predictable patterns that mirror net load.[9] The net load usually implies lower prices in the later morning hours, after solar generation comes online, followed by higher prices in the evening, after solar generation goes offline. In the spring, storage resources have the ability to buy energy when prices are lowest early in the morning, sell during the morning ramp, buy energy again when solar is fully online, and sell during the peak net load hours when prices are highest. Figure 8 below illustrates sample load and net load curves for a day in March. This chart shows that a resource could purchase energy during the lowest net load periods of the day (orange highlight) and sell during the highest net load periods of the day (green highlights). This specific day also shows that there could be an opportunity for this resource to charge prior to the morning peak, during hours ending 3 to 5 (not highlighted).

[8] Currently the CAISO's interconnection queue (Up to cluster 12) has over 230 projects both stand alone and hybrid energy storage totaling up to 48,559 MW.
[9] Net load is gross load less solar and wind generation.

Figure 8: Net load on March 15, 2019



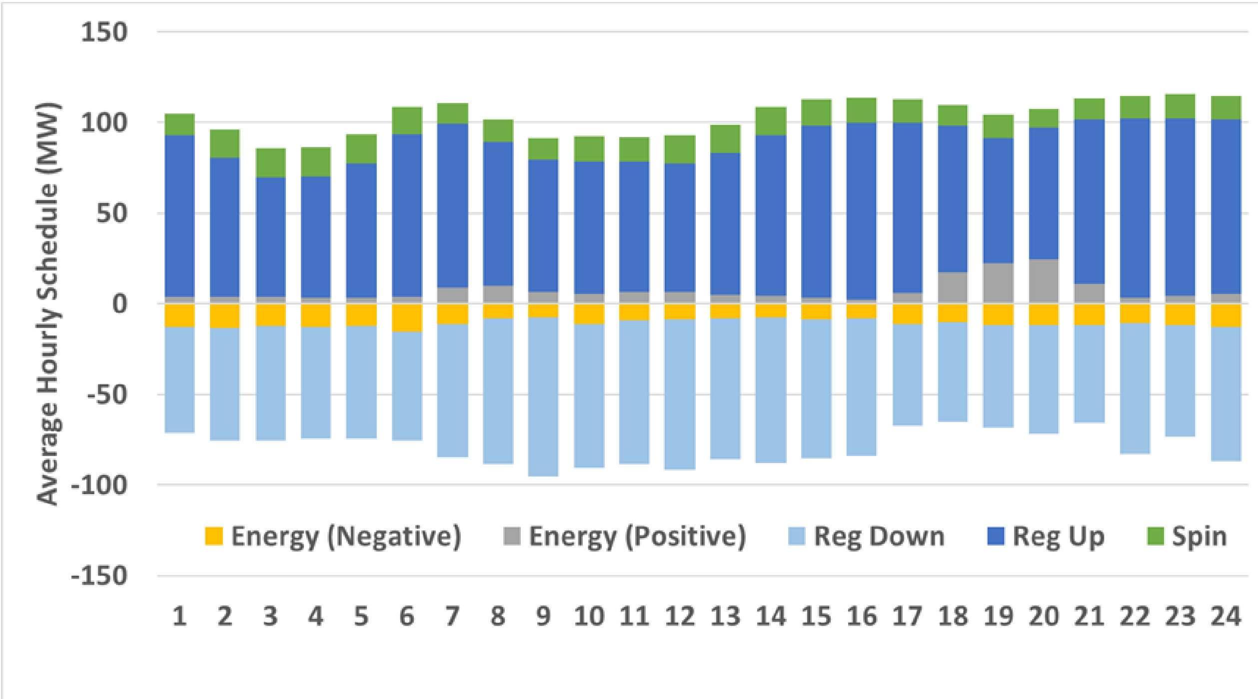
In the real-time market, storage resources may also have the opportunity to respond to short-term price spikes in low supply or oversupply conditions. In low supply conditions, the market often conveys high system marginal costs, which can be up to a $1,000/MWh penalty price for the power balance constraint. Conversely, in oversupply conditions, market prices can drop as low as -$150/MWh as a penalty price for the power balance constraint. Because storage resources have the ability to ramp quickly, they are well suited to take advantage of these prices in the real-time market.

Resources are able to collect revenue for providing ancillary services, such as regulation, by responding to automatic generation control signals in the market. Revenues from providing ancillary services to the market may be lower than revenues earned in the energy market, but generally come with awards that require the resource to provide less energy overall. This is advantageous for storage resources that have to purchase energy from the grid, encounter efficiency losses on energy purchased, and will eventually require maintenance because of charging and discharging.

As stated earlier, the CAISO operates about 150 MWs of storage resources today. Most participate as resource adequacy capacity. These resources receive compensation for their capacity, which make up a large component of the resource's total revenues. Although energy storage participates in the day-ahead and real-time markets, a majority of the 150 MWs sell very little energy into the system.

Figure 9 illustrates that most of the capacity for energy storage clears in the ancillary service market to provide regulation.

Figure 9: Average hourly schedules for storage resources (July-Dec 2019)



The data shown in
Figure 9 supports the CAISO's assertion that energy storage resources are incentivized to reduce cycling through regulation services and only provide energy in the day-ahead or real-time market when prices are high. Several factors lead to this behavior. First, a majority of energy storage technologies participating in the market are lithium-ion based devices and have cycling limitations due to manufacturer warranties or performance guarantees. Second, storage resources receive a capacity payment from resource adequacy to reflect fixed costs. The majority of the fixed cost represent warranty contracts that specify an amount of cycling the resource can achieve over a pre-defined time horizon.[10] A typical warranty for a four-hour storage device may allow for one cycle, a full discharge and charge, per day over ten years of operation. If the resource exceeds the limit, it could void its warranty, or reduce the "guaranteed" calendar life of the battery.

The CAISO believes the current warranty constructs and capacity payments for battery storage resources may not reflect the true costs of owning and operating these devices. These physical and contractual constraints may be impeding these resources from wanting to shift large tranches of energy from the afternoon to evening in the energy market to help integrate renewable resources like solar PV. Further, it is unclear if actual price spreads in the electricity market are sufficient to clear any hurdle that would make it economic for these resources to shift large quantities of energy. This is in part due to data showing that the average maximum possible spreads to move 4 hours of energy during the day are just over $40/MWh, and the spreads in the morning hours –

[10] CAISO staff learned this from discussions with multiple parties that operate storage resources in the market.

when present – are less than $20/MWh on average. The CAISO's objective is to build a construct for storage resources that will accurately reflect true costs, and may be used to mitigate resources when true costs are below observed market prices.

Proposal

The CAISO is proposing a default energy bid applicable to all storage resources on the system. This default energy bid will be representative of marginal costs for storage resources, calculated from a methodology outlined in this policy initiative. Furthermore, each energy storage resource will submit parameters to the CAISO that are verified, stored in master file, and are subject to review to inform calculations for approximating actual marginal costs.

In the CAISO's initial straw proposal, several possible methodologies to model storage resource costs were introduced. These included additional adders on existing variable cost default energy bids, an estimated cost methodology to allow storage resources to discharge during certain high price hours, and a methodology to model true costs for a resource.

In the revised straw proposal, the CAISO proposed a more complex default energy bid that more closely reflected actual marginal costs for energy storage operations. This default energy bid set up a four part default energy bid framework that included cost categories for energy purchased, efficiency losses, cycling costs and opportunity costs.

The revised straw proposal included a significant amount of detail about the cycling costs incurred when storage resources are operating. These costs are particularly relevant to lithium-ion storage resources and are incurred as batteries charge and discharge, which causes the cells to degrade. In turn, this causes the cells to be less effective in total charging capability, and eventually requires cell replacement. Since this degradation cost is strictly associated with the operation of the resource, it is a marginal cost and should be included in the default energy bid. However, this cost is difficult to model because it is non-linear in nature, may increase with the total depth of discharge of the resource, and may be technology or chemistry dependent.

The details outlined in the revised straw proposal included a dynamically calculated default energy bid that could change on an interval-by-interval basis directly with depth of discharge or specific dispatch for storage resources. Currently, the CAISO does not update default energy bids at any time during the day, and this would be a large departure from that paradigm.[11] The paradigm previously proposed would allow for default energy bids to change throughout the day.

This second revised straw proposal still includes the four cost categories outlined in initial versions of the paper, however it greatly simplifies the approach for estimating cycling costs for these resources and eliminates the dynamic nature that was previously proposed. This simpler calculation, may not be as accurate, but will reduce

[11] The ISO will update default energy during the day in cases where there is extreme gas price volatility. This process is meant for updates in very rare cases.

implementation burden and should be more straightforward for use by market participants.

4.1 Default Energy Bid Formulation

To apply local market power mitigation, the CAISO determines cost components to include in the default energy bid for storage resources. Costs for energy storage resources fall into four separate components and are described in detail below:

1. Energy Costs
2. Energy Losses
   - Parasitic losses
   - Round-trip efficiency losses
3. Cycling Costs
4. Opportunity Costs

Each of these four components are included in a default energy bid calculation outlined in Equation 1. Each component is described in the text further below.

Equation 1: Storage Default Energy Bid

$$Storage\ DEB = Max\left[\left(\frac{En}{\lambda} + CD\right), OC\right] * 1.1$$

Where:

En: Estimated cost for resource to buy energy
λ: Round-trip efficiency losses
CD: Cost to discharge
OC: Opportunity Cost

Because a +/- 200 MW storage resource could back generation down from 200 MW to 100 MW or charge at -200 MW instead of -100 MW in an effort to increase prices in local areas, the CAISO proposes that the default energy bid be applied to the entire output of a storage resource, not to only the discharging portion of the resource bid. The CAISO is proposing to mitigate resources for the full range of output including the entire charging and discharging range.

The formulation for the default energy bid outlined in Equation 1 above includes a variable 'CD' to account for the cost for a resource to discharge. This value will be zero for the entire charging portion of the bid. Therefore, for any market interval the default energy bid will always be a constant value for the entire charging portion of the portion of the resource's operating range. This calculation will always ensure that the default energy bid is monotonically increasing with output.

4.1.1 Energy Costs

Storage resources are different from traditional resources on the CAISO system. For example, gas fired generators have an available fuel supply that is converted to energy, and the heat rate, which describes the efficiency of the resource, informs the resource's marginal cost. Storage resources "buy" energy from the grid and sell that energy back to the grid by discharging at a later point in time. When a storage resource discharges, the impacts to the grid are identical to a traditional generator running.

It is critical that a value approximating the costs of energy purchased through the wholesale market be included in the default energy bid for storage resources. For example, if a storage resource buys energy at the lowest prices of the day at $10/MWh, it will have significantly lower costs than when energy costs are $50/MWh. Energy purchased at higher costs implies that sales need to be made at higher prices to maintain the same price spread.

The CAISO proposes a methodology to estimate costs that a storage resource may pay to charge. This value will be applied to default energy bids used for storage resources.

The methodology will use current day-ahead prices to estimate the marginal cost a storage resource may pay to procure energy in the day-ahead up to its full capacity. In the case of a 4-hour storage resource, this formula would be the 4th expected lowest hour of prices in the upcoming day.[12] This is expressed in Equation 2.

Equation 2: Energy Costs

$$En_t^{\delta} = En_{t-1}^{\delta} * Max\left(\frac{DAB_t}{DAB_{t-1}}, 1\right)$$

where:

En: Expected energy price
DAB: Day-ahead bilateral hub
t: Interval (day)
δ: Storage duration for the resource (i.e. 4 hours)

The formula is flexible and can represent the marginal price a resource pays for energy in the previous day if the energy is already purchased, or if the resource purchased energy the upcoming day. Further, this calculation will be performed for each resource, and expected prices will be calculated based on past prices at this resources location.

Each storage resource will have a representative bilateral electricity hub that will be used to calculate these expected prices, such as North-of-path 15, South-of-path-15, mid-Columbia, etc. These hubs will serve to scale current observed prices to day-ahead prices. The scaling will not be applied if day-ahead bilateral prices were higher for the current day than the successive day. Not applying a scalar may represent marginal prices that a storage resource could have paid to purchase energy, if energy was purchased today.

[12] For example, if prices were $45, $35, $32, $30, $27, $31, $40; the fourth lowest hour would be $32.

This calculation is not representative of the average price that a resource pays for energy and the CAISO is planning analysis for a future iteration. However, the price estimates are generally reflective of prices that a resource might purchase energy at, and may even overstate the average amount paid if the resource is performing one cycle per day or less.

Currently, the CAISO is not considering a methodology that includes the actual expected load from prior days. This may not be necessary as these load values should be internalized in the bilateral hub prices that are used to scale past prices.

4.1.2 Energy Losses

Generally, parasitic and round-trip efficiency losses may impact energy storage resources. Parasitic loss is the energy lost over time when energy is stored in a battery. Parasitic losses are calculated anytime a storage resource is charged. Because parasitic losses reduce the amount of energy stored in the battery, compared to the energy used to charge the battery, this factor can be accounted to scaling up the estimated price paid for energy. The energy loss inflates the amount of money that must be recouped from the sale of the stored energy when sold.

Currently, the CAISO is not proposing a methodology to account for parasitic losses. These costs may be accounted for by the storage resource's average state-of-charge and a variable describing how much that state-of-charge degrades over time. The CAISO requests stakeholder suggestions on how to incorporate such a calculation into the proposed default energy bid.[13]

The CAISO is proposing to account for round-trip efficiency losses account for energy that is lost due to the inefficiencies of charging. For example, a resource purchases and withdraws 10 MWh of energy from the grid, but is only able to discharge a total of 9.5 MWh of energy. Round-trip efficiency losses are measured as a percentage and typically range from around 85%-95% for lithium-ion resources.

4.1.3 Cycling Cost

The previous version of this paper, the revised straw proposal, included a description of a complex modelling approach for the cycling costs for storage resources. This second revised straw proposal outlines a significantly simplified approach to model cycling cost in a more general way. Much of the thinking in this portion of the paper was derived from the deep-dive conversation between ISO and stakeholders at the ESDER 4 working group that the ISO hosted in December. This conversation centered on expectations for operating costs that batteries developers are envisioning for resources coming online in response to requests for offers (RFOs), to meet energy capacity needs on the California system in the next few years and in response to CPUC thresholds.

[13] Parasitic losses may be more applicable for some existing storage resources currently on the system. Most new lithium-ion storage builds have relatively little parasitic losses.

From the workshop hosted in December, the ISO learned that the actual operating costs for many of the resources that will or could potentially be built and interconnected to the system, are designed specifically to optimally accomplish a particular operating behavior on a daily basis. This behavior may be configurable, however, it generally must be specified prior to the battery being developed. Many of the batteries are being built to optimally perform one cycle per day, which includes charging the battery once for four hours and discharging the battery for four hours later in the day.[14] These specifications are a direct result of the CPUC RA counting rules that state that resources are only able to count for resource adequacy for the amount of energy they are able to provide consistently during a minimum four hour period.

Because storage resources are designed to these minimum specifications, they generally experience a relatively consistent cost while operating within their design criteria, say 1 cycle per day, and significantly higher costs when operating at higher levels, say while operating beyond 1 cycle per day. Although these costs are generally impacted by the factors described in earlier versions of this proposal, which may include cycle depth, ambient temperature, current rate, and average state-of-charge, the impact may only be appreciable when the resource is operating within the bounds of where it was specifically designed to operate. Specifically, the impact of each of these factors may be relatively small compared to the cost to operate a typical storage resource that may be built on the CAISO system beyond one cycle per day.

Many of these factors and how they impact cycling costs were explored in great detail in earlier versions of the paper. Although this work was useful, the approaches to model the specifics of these costs can be very complicated and exceed the CAISO's current computational capabilities.

In this proposal, the ISO updates the proposed calculation for cycling costs to correspond to a value that represents operating a storage resource beyond the specified range of performance that the resource was designed for. For example, this might be operating beyond one cycle for most of the new storage resources that may likely be built on the system over the next few years.

Although there are relatively few resources in service on the grid today, there are many manufacturers developing and testing batteries that could be integrated within the next few years. In discussions with battery manufacturers and experts in developing batteries, the CAISO has learned that many anticipate costs related to cycling and operating, to generally be less than $30/MWh for most new lithium-ion resources. The ISO notes that several developers have declared large differences between marginal cycling costs for different storage projects with different chemistries, even within the lithium-ion technology. Generally this number would be applicable while the battery operates within its design specification. Conversations with a variety of battery manufacturers have been informative as to the costs of storage resources operating beyond their design specification, which may be between 2 to 3 times larger than those costs when operating within them.

Although the CAISO is planning to allow the higher of these values to be included in the default energy bid for the storage resource, all values will need to be validated by the

[14] Some resources may be designed with the purpose of delivering just over 1 cycle per day to allow for some additional flexibility. These resources may be designed to deliver 1.1 or 1.25 cycles per day.

CAISO before they may be used in default energy bids. Validation, in the form of estimates from storage manufactures may suffice for the CAISO to review. In the future, as more storage resources are connected to the grid, the CAISO may develop guidelines for acceptable values, similar to guidelines for other values reviewed by the CAISO.[15]

4.1.4 Opportunity Costs

The market power mitigation tool can replace submitted bids with CAISO calculated default energy bids. In the event that these bids are lower than the true cost to operate a resource, the tool may force an inefficient dispatch. Storage resources can only generate until its stored energy is depleted before it needs to recharge. To avoid being discharged before the optimal time, a resource with limited availability should have an opportunity cost included in its default energy bid. These opportunity costs include the value to the resource owner from not running during a particular interval and saving stored energy until a later time when prices are higher.

This proposal includes a construct where the default energy bid may change with the state-of-charge of the resource. Generally, when the state-of-charge for the resource is high, the default cost to discharge the resource will be low, and when the state-of-charge is low, the cost to discharge the resource will be high. A scenario may exist when the resource is charged at full or nearly full state-of-charge, and that portion of the default energy bid will be particularly low. If the resource is fully charged and the resulting default energy bid is $10/MWh and the current price is $20/MWh, it will indeed be profitable for the resource to discharge and receive this revenue. However, this may be sub-optimal as prices for the successive four hours may be $100/MWh. In this example, the resource would optimally wait to discharge stored energy, until the later hours when prices are higher.

This example is highly simplified, but it illustrates the need for inclusion of an opportunity cost adder in the default energy bid for storage resources. In this simple example, an opportunity cost increasing the total default energy bid to $100/MWh is appropriate for this resource. The inclusion of opportunity costs in the default energy bid is further complicated when a resource is capable of buying and selling energy for multiple hours, and buys or sells energy in the real-time market and experiences economic losses.

The CAISO proposes including the highest price, corresponding to the storage duration of the resource in the default energy bids for storage resources. For example, if a specific storage resource is capable of storing 4 hours of energy, the opportunity cost included in the default energy bid will be equal to estimated prices in the 4th highest hours of the day.[16] The process used to estimate these costs will be the same outlined to estimate energy costs in the section above. This methodology will include looking at

[15] These may include other values collected and verified by the ISO, such as major maintenance costs for specific resources.
[16] For example, if prices are $45, $35, $32, $30, $27, $31, $40; the fourth highest hour would be $32.

expected prices in the future, based on previous known prices and expected futures prices.

Equation 3: Opportunity Costs

$$OC_t^{\delta} = OC_{t-1}^{\delta} * Max\left(\frac{DAB_t}{DAB_{t-1}}, 1\right)$$

where:

OC: Opportunity cost
DAB: Day-ahead bilateral hub
t: Interval (day)
δ: Storage duration for the resource (i.e. 4 hours)

Equation 3 is formulated in a similar manner to Equation 2, which expresses the expected costs for energy, outlined above.

Using a value less than the total duration of the resource could lead to potential issues with the dispatch of the resource. Suppose that the four highest priced hours have energy priced at $100/MWh and these hours occurred in one four hour block. Setting the opportunity cost at a lower value, such as $90/MWh could lead to inefficient outcomes. This would be the case if actual prices were $95/MWh in the hour directly preceding the four hour block when prices are $100/MWh may have the resource discharge energy when prices are less than the maximum for the day.

If the derivation for the opportunity cost is dynamic, it may be possible to apply enhanced logic as to what the opportunity cost would be. A dynamic approach is not currently being considered.

4.2 Input parameters

There are several equations in this section of the proposal outlining the calculation for a default energy bid for storage resources. Some of these equations include variables that characterize costs that are specific to individual resources. The CAISO contends that these values are relatively stable over time, but also are generally unknown to the CAISO. Similar to existing gas resources today, the CAISO plans to collect this data for all storage resources in the future. This data will be collected via the CAISO master file process that is already in place to capture resource specific data.

Master File variables that will be collected for storage resources:

λ: Round-trip efficiency losses
δ: Storage duration for the resource (i.e. 4 hours)
$\boldsymbol{\rho}$: Cell degradation cost

Like other variables that are collected and stored in master file, scheduling coordinators for these resources will have requirements for submitting these variables to the CAISO. As with other master file data, CAISO will have descriptions of what this data should represent, how the data should be submitted and what, if any, documentation should accompany this data when it is submitted to master file. Finally, as with all data submitted to the CAISO, there will be an obligation on scheduling coordinators to ensure that this data is up to date and accurate for all resources.

4.3 Alignment of Default Energy Bid with Market Bids

The CAISO believes that there should be alignment between the default energy bid values and the bids a resource is able to submit to the market. As noted above, this default energy bid should reflect marginal costs for storage resources. The market will mitigate bids to these costs if local market power mitigation is triggered. Each of the suggested approaches outlined above includes costs that change dynamically with the resource’s state-of-charge value or dispatch instruction. Today, all scheduling coordinators are required to submit bids into the CAISO markets prior to each operational hour, and may submit bids for multiple hours at a time. Once the hour begins, these bids are fixed for the duration of the hour and will not be changed. Further, these bids are expressed in $/MW and are currently not set up to vary based on any resource parameter such as a state-of-charge. This causes an inconsistency between values that a storage resource may bid and the formulation the CAISO will use to calculate a default energy bid.

Because of the need to align bidding capability with the default energy bid, the CAISO proposes to allow bids for storage resources to vary based on state-of-charge or dispatch instruction, so that it is possible for a resource owner to submit bids that mirror values that CAISO could use for mitigation.

4.4 Alternative Default Energy Bids

Although the CAISO is striving to develop a functional default energy bid that will reasonably approximate costs for most storage resources, it may not be feasible to develop a methodology that will work for all storage resources and technology types. Therefore, resources always have the ability to apply for a negotiated default energy bid if the proposed methodology outlined is insufficient. Additionally, the CAISO has started a stakeholder initiative to update allowable operations and maintenance values for all resource types, including storage. These values will apply to variable cost default energy bids and may also be sufficient for some storage resources. Further, the operations and maintenance adders can be negotiated with the CAISO at a resource specific level, at a justifiable cost.

5 Establishing Parameters to Reflect Demand Response Operational Characteristics

Certain demand response resources may not have a minimum operating level similar or analogous to conventional resources, in which it registers a Pmin/Minimum Load value of 0 MW in the CAISO Master File. Experience has shown that a Pmin of 0 MW presents operational challenges for certain demand response resources. Today, long-start resources (equivalent of day-ahead only DR) committed in the residual unit commitment (RUC) process are started and instructed to their Pmin so that they are available for dispatch and can ramp in real-time when needed. For demand response, the market instructs the demand response resource to its Pmin (respecting its minimum run time) and assumes the resource is ready to be dispatched and reduce load when instructed.[17]

The scenario above can result in a rational and economic dispatch where a demand response resource receives multiple and subsequent instructions to curtail load in one interval and return to Pmin of 0 MW in another interval. While the CAISO market systems are acting rationally and see the demand response resource as economic and capable of moving between its Pmin and Pmax in any interval, certain demand response resources are inflexible and can only provide a limited number of sustained responses from their Pmin.

The CAISO continues to highlight a combination of market parameters and bidding options as proposed methods for demand response resources to effectively reflect operational limitations. The CAISO has received positive feedback on ability for many demand response resource to benefit from these options. However, comments received from stakeholders have identified specific demand response program designs that may not be effectively characterized utilizing these available and emerging options. Program designs, when characterized as a resource, are constrained with a limited number of starts and a set number of hours available for dispatch within a day. To optimize demand response resources with these programmatic constraints, the CAISO is proposing a maximum daily run time parameter so that the market can optimize demand response resources with daily hourly limitations that may not be manageable utilizing the current maximum daily energy limitation parameter.

5.1 Scenarios utilizing current market parameters

Option 1: Pmin = 0 MW and resource registers startup costs

In ESDER 3, the CAISO designed the hourly and 15-minute bidding options for proxy demand resources to extend notification times and longer duration interval dispatches. This will allow for effective real time dispatching of PDRs with a Pmin = 0 MW. Additionally, with the implementation of the Commitment Cost and Default Energy Bid Enhancements[18] and Commitment Cost Enhancements[19] initiatives, non-gas resources have ability to submit a minimum load cost and enhanced capability to have a resources start-up cost be independent of Pmin, allowing for non-zero start-up with Pmin = 0MW.

If a proxy demand resource (PDR) were to elect an hourly bid option and define a non-zero dollar commitment cost at a Pmin of 0 MW, the resource would no longer be a zero cost option in the CAISO's residual unit commitment optimization. Additionally, once

---

[17] Definition of minimum run time
http://www.caiso.com/Documents/Section34_RealTimeMarket_asof_May2_2017.pdf

[18] Commitment costs and default energy bid enhancements (CCDEBE) policy page
http://www.caiso.com/informed/Pages/StakeholderProcesses/CommitmentCosts_DefaultEnergyBidEnhancements.aspx

[19] Commitment cost enhancements (CCE3) reference material
http://www.caiso.com/informed/Pages/StakeholderProcesses/CommitmentCostEnhancements.aspx

committed in the residual unit commitment process, the proxy demand resource would only be dispatched off its Pmin in hourly blocks per its elected bidding option.

Even with these additional PDR resource parameter options, challenges remain. These include a demand response resource's inability to respond to multiple and variable dispatches from Pmin based on program limitations on the number of curtailments available within a day. Additionally, scheduling coordinators for demand response resources have hesitated to submit commitment costs and have asked the CAISO to provide guidance.

The benefit of this option is the ability for a demand response resource to implement these changes when the policy proposals (ESDER 3B, CCDEBE, CCE3) are approved by FERC and implemented.[20]

Option 2: Non-zero Pmin with minimum load costs (minimum load cost)

During the March 18, 2019 working group meeting, the CAISO presented a scenario in which demand response resources could register a Pmin close to its Pmax and assign a minimum load cost.[21] The optimization will consider the non-zero Pmin and associated minimum load cost to determine if it is economic to dispatch a resource to its Pmin (close to Pmax). Additionally, the resource could utilize the maximum daily energy limit to identify a MW/hour quantity it can only be awarded to account for the limited run time of a demand response resource.

This proposed option requires the scheduling coordinators to determine and provide a minimum load cost.

The benefit of option two is the ability of scheduling coordinators to use parameters that exist today without any dependencies on current or future implementation timelines.

In response to Southern California Edison's comments of the limitations of the maximum daily energy limit, if the resource identifies its Pmin at .01 MW below its Pmax, the CAISO will consider the minimum load cost and non-zero Pmin in the residual unit commitment process. If the resource is committed, it will be dispatched to its Pmin, and the CAISO will respect the maximum daily energy limit. Additionally, inflexible demand response resources that are not able to respond to varying dispatches will receive a consistent award at the non-zero Pmin value.

5.2 Maximum Daily Run Time Parameter

Based on stakeholder feedback, the CAISO is no longer proposing a "maximum run time" but instead is proposing a maximum daily run time parameter to optimally resolve the issue of demand response resources being dispatched beyond program limitations. The issue occurs when the market observes a Pmin of zero as an "on" state and moves dispatches between its Pmin of zero and a non-zero value. Introducing a maximum

[20] CCE3 and ESDER3 Phase A has been approved by FERC and implemented. ESDER 3 Phase B and CCDEBE have not been filed with FERC, as both await technology development.

[21] Tariff Appendix A "Minimum Load Costs – The costs a Generating Unit, Participating Load, Reliability Demand Response Resource, or Proxy Demand Resource incurs operating at Minimum Load, which in the case of Participating Load, Reliability Demand Response Resource, or Proxy Demand Resource may not be negative. Minimum Load Costs may be adjusted pursuant to Section 30.7.10.2, if applicable."

daily run time parameter would allow a demand response resource to identify the maximum number of hours the resource could be "on" over the course of a day. This parameter, in combination with the currently available start-up constraint, provides for ability to characterize program constraints along with flexibilities that can be considered in their optimization.

The parameter will be captured in master file and represent the maximum number of hours a demand response resource can be committed and/or dispatched on a daily basis. The parameter components and requirements are summarized below:

- Master file parameter representing a daily maximum number of hours the resource can be committed and/or dispatched.
- Parameter is an option under master file and not a requirement.
- Applicable for both proxy demand response and reliability demand response resources.
- Resources must have a minimum 1 MW curtailment capability and register a Pmax value that is equal to or greater than 1 MW.

The CAISO is establishing the 1 MW threshold due to concerns with degradation of market system performance with the utilization of an additional constraint by a significant number of resources with fractional MW offerings. As the number of participants in the market has expanded, the CAISO is concerned with maintaining the performance of its market systems. In general, implementing discrete constraints in addition to binary variables, have a large impact on market performance. On most days, the day-ahead market is evaluating bids for over 800 proxy demand resources. If the CAISO allowed a maximum daily run time parameter for all demand response resources regardless of size, the resulting impact on performance could put the 1 PM day-ahead market publishing deadline in jeopardy. The CAISO has developed these requirement restrictions to minimize the known risk to market performance.

The examples below illustrate how the proposed parameter will be utilized in the market's optimization of demand response resources.

Example 1: Maximum Daily Run Time Constraint with Day Ahead Commitments

Figure 10 and Figure 11 represent a demand response resource with a Pmin of 0 MW, start-up >= 1, a minimum run time of 1 hour, and a maximum daily run time of 5 hours.

Figure 10 illustrates the resources commitment in the day-ahead market to a Pmin= 0 MW to its maximum daily run time limitation and receiving contiguous dispatches in real-time.

In this example, the resource is committed for its maximum daily run time of 5 hours with its initial start-up to Pmin.

In real time the resource is dispatched contiguously in the hours in which it was committed, from HE17 to HE 21. This example illustrates how a resource with a start-up = 1 would receive a contiguous real time dispatch at its maximum daily run time.

The characteristics of this resource will always result in a contiguous real time dispatch of the resource for a number of hours up to its maximum daily run time.

The CAISO has previously expressed concern with demand resources maintaining a Pmin of zero with a maximum daily run time parameter resulting in instructions to a Pmin of 0 MW leading to limited or no provision of curtailment. Therefore, the CAISO will work with stakeholders on addressing the inefficiencies and market concerns as it develops the proposal.

Figure 10: Contiguous dispatch in real-time market

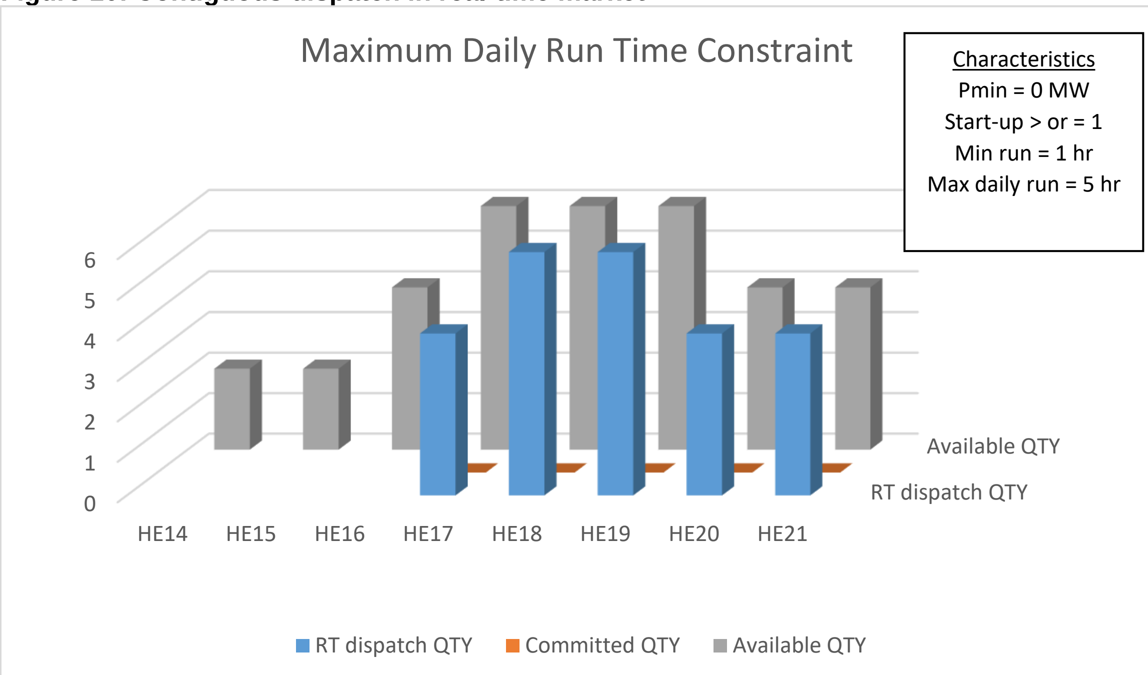
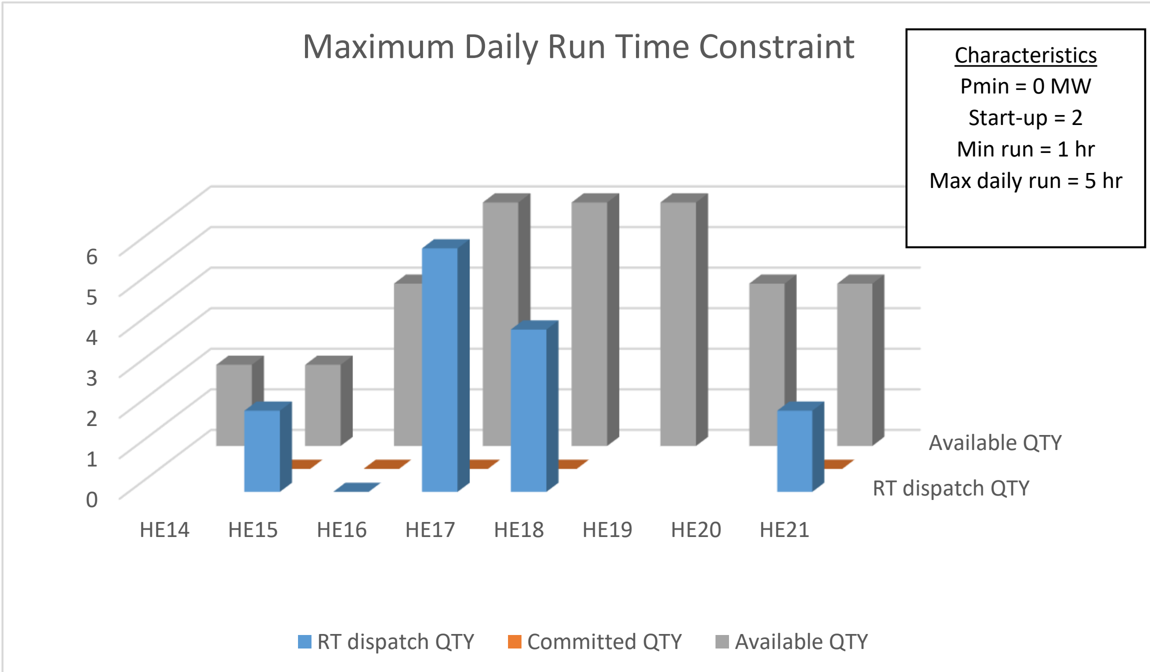


Figure 11 illustrates the resources commitment in the day-ahead market to a Pmin= 0 MW to its maximum daily run time limitation while receiving non-contiguous dispatches in real-time.

In this example, the first start up committed the resource for 4 hours with a subsequent start-up to Pmin for 1 hour, honoring both the start-up and maximum daily run time constraints.

In real time the resource is dispatched in HE15 and again in HE17-18 after being instructed back to its Pmin of 0 MW. The resource is again called in HE 21. This example illustrates how a real time dispatch respecting the resources start-up and maximum daily run time is respected for a resource with Pmin = 0 MW. The CAISO recognizes this as a shortcoming of demand response resource choosing to register with a Pmin of 0 MW while utilizing a maximum daily run time and start-up > 1.

Figure 11: Noncontiguous dispatch in real-time market



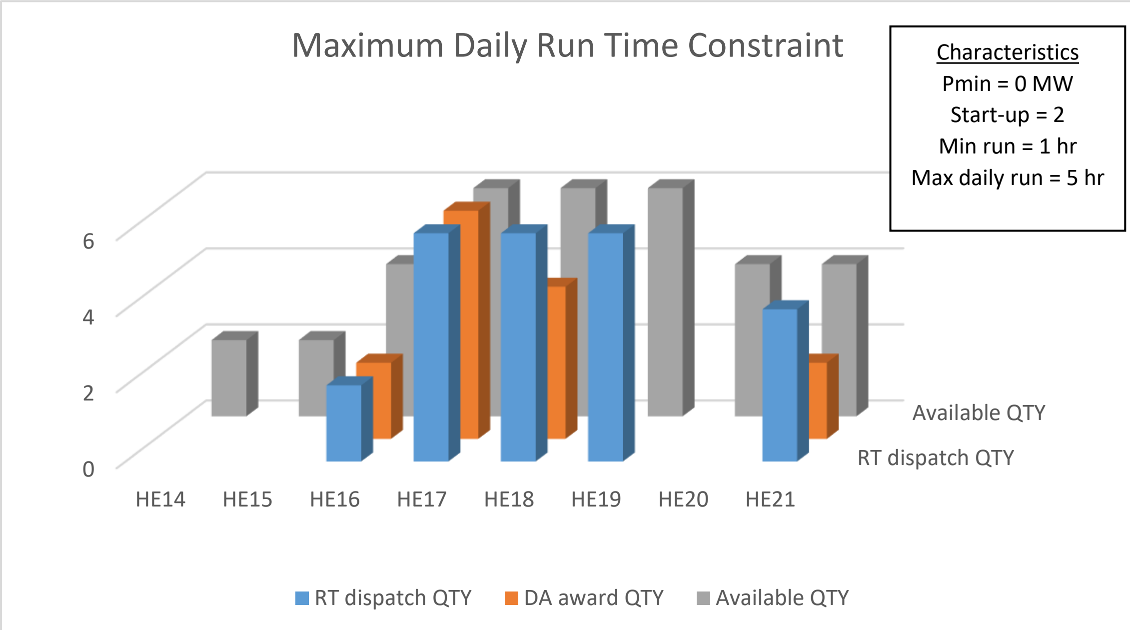
Example 2: Interaction between day-ahead and real-time market awards

Figure 12 represent a demand response resource with a Pmin of 0 MW, start-up = 2, a minimum run time of 1 hour, and a maximum daily run time of 5 hours and demonstrates how the CAISO optimization will consider the maximum daily run time constraint across both the day-ahead and real-time markets.

In this example, the resource is awarded in the day-ahead market for 3 hours with its first start up with a subsequent award for 1 hour with its second start-up, honoring both the start-up and maximum daily run time constraints.

Figure 12 illustrates the resource day-ahead market awards in for HE16-18 and HE21. In real time, the resource is not only dispatched for hours awarded in the day ahead but also for an additional hour contiguous to its day ahead award in HE19. In real-time, the optimization has feasibly dispatched the resource considering and respecting both start up and maximum daily run time constraints.

Figure 12: Resource receives awards in day-ahead and real-time market



6 Vetting Qualification and Operational Processes for Variable-Output Demand Response

The CAISO defines variable-output demand response resources as those demand response resources whose maximum output can vary over the course of a day, month, or season due to production schedules, duty cycles, availability, seasonality, temperature, occupancy, etc. For instance, certain demand response resources' output may vary with weather, like an AC cycling demand response program that can reduce more load on a hot day when air-conditioner use is high versus on a moderate day when air conditioner use is low. When a variable-output demand response resource provides resource adequacy capacity in the year-ahead or month-ahead timeframe, depending on conditions, the resource may be unable to deliver its full stated resource adequacy capacity in the day-ahead or real-time given its variable nature.

Many demand response resources also have availability limitations that affect a resource's ability to provide the energy associated with the RA capacity they provide. These limitations include hours of operability, duration, or number of event calls. As California transitions to a decarbonized grid, CAISO will likely rely more heavily on both variable and availability-limited resources. As such, it is critical to assess the ability of the new resource fleet, including preferred resources, to displace carbon-emitting generation while maintaining system reliability and serving energy needs every hour of the year.

The central tenet of the resource adequacy program is to ensure sufficient energy is available and deliverable when and where needed. As CPUC Commissioner Randolph stated, "*A successful Resource Adequacy program ensures that every part of California has instantaneous power to serve their customers every hour of the year. It is invisible to the public when it is functioning as it should, because power flows without curtailment* *or outages even when the grid is stressed*."[22] Thus, the inability to deliver energy associated with resource adequacy capacity because of certain known dependencies is a "visibly" significant issue. Currently, if a resource cannot bid its full qualifying capacity and deliver it under its must offer obligation, it jeopardizes the central tenet of the resource adequacy program. Additionally, resources incapable of meeting their net qualifying capacity value during the availability assessment hours will be assessed charges through the Resource Adequacy Availability Incentive Mechanism (RAAIM).[23]

A majority of demand response resources have dependencies that result in having a variable output (curtailment capability) even though they are treated under CPUC resource adequacy rules as capable of delivering their full qualifying capacity value whenever dispatched. This overstates their resource adequacy qualifying capacity capability and jeopardizes the CPUC's resource adequacy program and reliability.

To address this issue, the CAISO and the CPUC/local regulatory authorities must modify demand response resource adequacy and market participation rules to align with the following two principles.

1. The qualifying capacity valuation methodology for demand response resources must consider variable-output demand response resources' reliability contribution to system resource adequacy needs, and
2. Market participation and must offer obligations must align with demand response resource capabilities.

Operational capabilities of variable-output demand response resources change over the course of the day, month or season because maximum output is dependent on some variable condition like weather, availability, temperature, product production, etc. Increasing penetrations of variable resources, including certain types of demand response, make it important to quantify the contribution of these resources and their ability to serve system load when they are needed. For wind and solar resources, this assessment is done by determining the resources' Effective Load Carrying Capability (ELCC).[24] Once an appropriate qualifying capacity value is determined for wind and solar by applying the ELCC, the resource can fulfill its must offer obligation by bidding the amount it is physically capable of providing per its forecast. In this paper, the CAISO proposes to demonstrate how a similar methodology should be applied to variable-output demand response, including those with availability limitations.[25]

This issue will need further vetting and decision-making at the CPUC and with other local regulatory authorities since local regulatory authorities have jurisdiction over establishing resource adequacy qualifying capacity values. To encourage and advance

[22] CPUC News Blog; Commissioner Blog: Keeping the Lights On, by Commissioner Randolph, 2/22/2019, found here: https://www.cpuc.ca.gov/cpucblog.aspx?id=6442460494&blogid=1551

[23] The broader application of RAAIM is currently being reviewed in the RA Enhancements initiative: http://www.caiso.com/informed/Pages/StakeholderProcesses/ResourceAdequacyEnhancements.aspx

[24] ELCC is explained in detail below.

[25] It may not be necessary to apply an ELCC value or provide alternative market participation options for demand response resources that are neither variable nor availability limited if they can provide a fixed load reduction value over the course of the RA month.

this issue, the CAISO is seeking stakeholder input for its recommendations to the CPUC regarding the appropriate methodology for establishing qualifying capacity values for variable-output demand response. It also will discuss how to operationalize and accommodate variable-output demand response as a resource adequacy resource in the CAISO market once the CPUC and local regulatory authorities have adopted such a methodology.

6.1 Stakeholder Comments

The CAISO summarizes the stakeholder comments received on the Revised Straw Proposal here.

Stakeholders encourage more definition around what classifies a DR resource as variable-output. Fundamentally, if a resource cannot deliver its shown net qualifying capacity amount under the must offer obligation because of dependencies as described previously in this paper, then it is a variable output demand response resource. SCs can easily make this determination based on whether they know they can confidently provide a fixed MW reduction at any time to meet the CAISO's resource adequacy must offer obligation over an RA compliance month.

Some stakeholders suggest clarity on the applicability of the proposal considering different DR programs have differing degrees of variability. The CAISO believes an ELCC methodology can apply to all demand response types that are variable, availability limited, or both. In other words, the degree of variability is less the issue then the fact that they are variable, *i.e.* they cannot deliver a fixed net qualifying capacity value. Such a methodology should consider both availability (i.e., duration, maximum calls, program hours) and variability to inform the qualifying capacity value. An ELCC study is an appropriate and industry-accepted way to assess and compare the capacity value of resources that exhibit variability and or have limited availability to support the system.

Many stakeholders requested additional clarification and justification on 1) the CAISO's view of the purpose of demand response as a resource adequacy resource and 2) the CAISO's desired shift to an ELCC methodology for evaluation the capacity value of demand response. The CAISO understands that demand response resources have unique characteristics that necessarily limit their availability over the course of the RA month and year. The CAISO agrees with stakeholders that not all RA resources are needed every hour of every day depending on system conditions. However, the CAISO must ensure the *portfolio* of shown RA resources can meet load 24 by 7. As California Public Utilities Code 380 Section C states, "Each load-serving entity shall maintain physical generating capacity and electrical demand response adequate to meet its load requirements, including, but not limited to, peak demand and planning and operating reserves" (emphasis added).

As such, counting rules for resource adequacy resources should reflect their availability to the system when they are needed. It is important to assess the ability of preferred resources to displace traditional thermal generation, while maintaining system reliability and serving energy needs every hour of the year. Decarbonizing energy supply requires replacing both the capacity AND energy provided by the gas-fired fleet; not just capacity substitution focused on peak demand hours. An ELCC methodology will inform how such resources support system reliability and which resources to invest in to provide the least cost, best fit replacement of GHG emitting resources in the context of system reliability and achieving California's clean energy goals.

Stakeholders are supportive of allowing variable-output DR to bid their availability to fulfill their must offer obligation, rather than the static NQC value. Several stakeholders indicated their availability can be reflected under the timeline for bid submission (hourly at T-75). Additionally, some stakeholders indicated that requiring resources to have more stringent data submission requirements would likely be cost prohibitive, without providing additional benefits. Given this, the CAISO is open to allowing resources to bid their availability given resource availability will not change throughout the course of the hour and the appropriate controls are in place to ensure bids accurately reflect availability. CAISO provides more detail on the must offer obligations and bidding requirements in Section 5.3 below.

6.2 Determining the Qualifying Capacity value for variable-output demand response

Local regulatory authorities are responsible for determining the qualifying capacity values for resource adequacy resources. To set the qualifying capacity for demand response resources, the CPUC adopted load impact protocols as a defined set of guidelines to estimate the load impacts of Investor Owned Utility and third party demand response programs. Load impact protocols are a combination of ex-post and ex-ante assessments of load impacts used to determine the load reduction capability of each demand response program. Ex-post impacts consider historical demand reductions during actual demand response events. Ex-ante load impacts estimate load reduction capability for each month using 1-in-2 and 1-in-10 peak conditions. Ex-ante impacts are forward looking and based on historical load impact performance. Load impact protocols rely on regression analysis to predict average customer load and estimate demand response program load impacts using independent variables including weather conditions, month, time of day, and day of the week. For demand response auction mechanism (DRAM) resources effective with the 2019 solicitation, the qualifying capacity is estimated based on historical performance data supplemented with disclosure of load aggregation data with reference to past test events or market dispatches of similar resources. It is important to develop appropriate qualifying capacity methodologies for utility, demand response auction mechanism, and third party demand response resources.

Through this initiative, the CAISO, with the input of stakeholders, will explore how ELCC values can be established for demand response. The CAISO intends to use the outcome of this initiative to inform the CPUC and other LRAs on how demand response could be valued considering its variable and availability-limited nature, and establish in the CAISO tariff default qualifying capacity provisions for LRAs who do not adopt their own qualifying capacity counting methodology.

ELCC background

ELCC is a probabilistic approach used to quantify the reliability contribution of a resources or class of resources. The CPUC currently uses this approach to determine the qualifying capacity of wind and solar resources. As a first step to determining the ELCC, the CPUC performs a loss of load expectation (LOLE) study to determine the expected average number of events during which system capacity is unable to meet CAISO system load. A commonly accepted LOLE reliability target is 0.1 days per year.

The ELCC quantifies the contribution of the resources or group of resources to resource adequacy by assessing the resource's ability to avoid a LOLE event considering inputs such as expected load, forced outage rates, transmission constraints, etc. When calculating the ELCC for wind and solar, a ratio of the ability of a resource to avoid LOLE compared to a perfect generator is used and a monthly, system-wide ELCC value to wind and solar resources to determine the qualifying capacity is assigned.

ELCC % = (MW of Perfect Generator) / (MW of resource being studied)

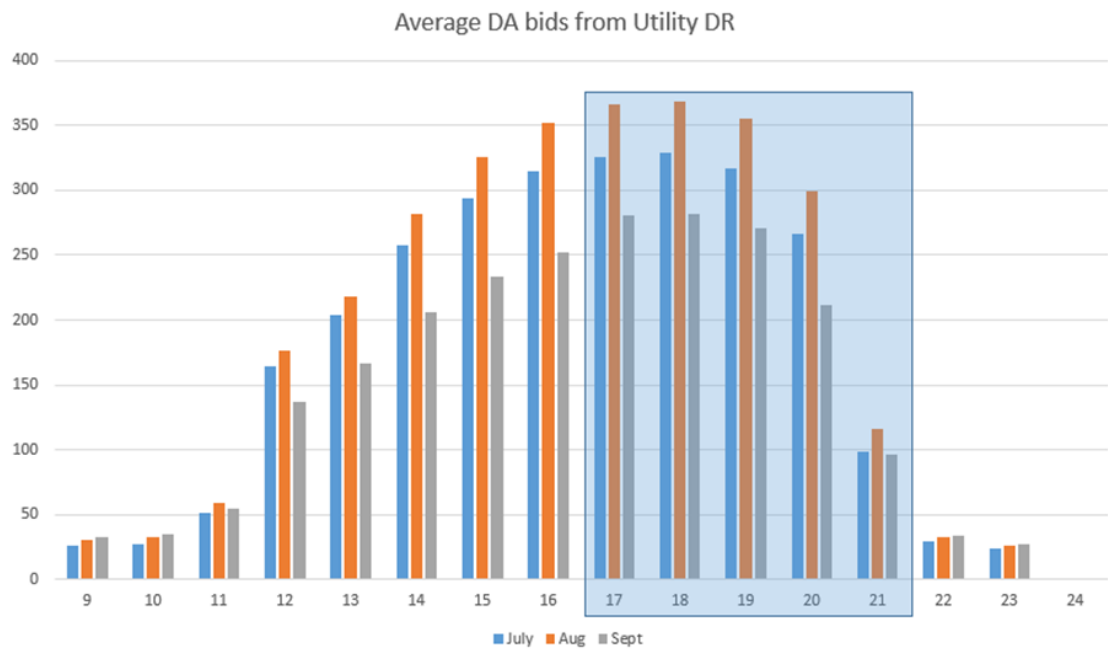
The ELCC value is a percentage applied to the nameplate capacity of a resource to determine the qualifying capacity. For example, a perfect generator would have an ELCC equal to 100%. A resource with an ELCC of 50% would be half as effective at reducing LOLE as a perfect generator. If a solar resource had a nameplate capacity of 100 MW and a 50% ELCC, the resource adequacy qualifying capacity would equal 50 MW. As discussed below, because DR does not have a nameplate value like wind, solar, or other generators, an alternative method for determining the maximum capability of a DR resource should be defined.

Using ELCC to assess the capacity value of variable-output demand response

The CAISO believes the ELCC method can and should be applied to variable-output and availability-limited demand response resources. This type of assessment is appropriately applied to resources whose output is variable or potentially limited based on its use. Its application to variable-output and availability-limited demand response will provide a more accurate assessment of the actual load impact and load-sustaining capability variable-output demand response resource can provide the system.

The CAISO has observed bidding by demand response resources that suggests variability in the underlying load profiles of the resource. Figure 13 below shows average day-ahead bids on non-holiday weekdays from utility-operated demand response programs in July, August, and September of 2019. These programs are not shown on monthly resource adequacy supply plans and instead are credited toward the LSE's resource adequacy requirements by the CPUC. Because these resources are not listed on supply plans, they are not subject to the must offer obligation and associated RAAIM charges for not bidding in the availability assessment hours. The 2019 availability assessment hours (HE17 to HE21) are highlighted by the blue box. As the bid data reflects, utility DR available to the CAISO through bids varies over the course of the day and is not a flat shape.

Figure 13: Average Day-Ahead Bids from Utility DR (2019)



The shaped availability of utility-operated DR resources shows these resources do not provide a fixed load reduction in all hours of the RA month. As such, their capacity value is more appropriately assessed on the resources availability and capability when it is needed considering load levels and the contribution from the rest of the resource adequacy resource fleet. It is not appropriate to treat variable demand response resources as if they are fixed resource adequacy resources that are capable of delivering a fixed RA capacity quantity in all hours under their must offer obligation.

The current load impact protocols are too limiting and only considers a resource's own load reduction capability in the RA measurement hours of the monthly peak day. This does not necessarily align with when resources are needed to avoid a loss of load event when considering the availability of other resources on the system, especially as the system grows more dependent on variable energy resources and retires fuel-backed resources. The load impact protocols assess the load impact of an individual program rather than the reliability contribution of a resource given the availability of the rest of the resource fleet. The ELCC considers the ability of a portfolio of resources to avoid LOLE at a system level. It is important to consider the portfolio of resources because the reliability contribution of a resource or class of resources can vary depending on the makeup of the other resources in the portfolio used to meet the resource adequacy need.

Variable-output and availability-limited demand responses should be considered under an ELCC methodology to determine their qualifying capacity values since the ELCC can capture the incremental benefit of a demand response resource to system reliability across multiple hours while considering the impact of the entire demand response and variable energy resource portfolio.

Once an ELCC methodology is adopted for demand response, the CAISO believes resource bids could inform the ELCC calculation to reflect resource availability. As outlined in the section below, the CAISO proposes to allow variable-output demand response resources to bid their expected capability to meet their must offer obligation. Once demand response resources bid the amount they are physically capable of providing, the bids should accurately reflect the capability of the resource. This bidding profile could then be used as an input into the ELCC to evaluate variable-output demand response's reliability contribution.

Some stakeholders asked the CAISO how to determine a “nameplate” value for DR to apply an ELCC percentage to. The CAISO agrees with stakeholders that DR does not have a precise “nameplate”, like a wind, solar, or other generating units. However, the maximum capability of a DR program can and should be estimated using an established set of guidelines to determine the maximum MWs of load reduction a DR program can provide under 1 in 2 peak load weather conditions based on historical capabilities. Because the ELCC percentage would be applied to this value to account for variability, it appears reasonable not to further de-rate the maximum capability due to time of day, season, weather, etc. before the ELCC is applied. While the precise methodology for determining nameplate should be further refined, initial analysis can be done to calculate ELCC values based on profiles of demand response availability and apply them to the resource's Pmax and current NQC values as an initial starting point and point of comparison. The CAISO welcomes further input on this issue.

ELCC Study

Stakeholders have requested and the CAISO has committed to providing ELCC numbers for California demand response resources in the ESDER 4 initiative. In parallel with this initiative, the CAISO has contracted with Energy and Environmental Economics, Inc. (E3) to develop an analytical framework to evaluate the resource adequacy value of demand response using an ELCC. Through this effort, E3 will simulate the capacity contribution of demand response in their Renewable Energy Capacity Planning (RECAP) model. Results of this work will be presented to stakeholders throughout the ESDER 4 stakeholder process for stakeholder consideration. Initial results will be presented at the March 2, 2020 working group.

6.3 Market participation and must offer obligations for variable-output demand response

Resource adequacy resources have must offer obligations to bid into the CAISO market the amount of net qualifying capacity the resource has shown in their supply plan. Demand response resources on supply plans are required to bid into the CAISO markets according to tariff sections 40.6.1 and 40.6.2. In general, RA resources are required to bid into the day-ahead market its shown RA all hours of the day the resource is not on outage. The CAISO allows demand response to bid in the hours specified within their program established by the local regulatory authority. If the resource does not bid its shown RA in the availability assessment hours, it could be assessed a non-availability charge through RAAIM. Because most if not all demand response programs exhibit variability, and the QC valuation process gives DR a single value for the purposes of RA counting, resources risk being assessed RAAIM penalties in hours they cannot bid all of their shown resource adequacy capacity.

The CAISO proposes to address this issue by allowing variable-output demand response resources to bid the amount they are physically capable of providing, rather than the shown amount of net qualifying capacity, in order to meet their must offer obligation. Today, VERs receive this treatment. Scheduling coordinators for VERs must either use a forecast provided by the CAISO or submit their own CAISO-approved forecast. Bids are submitted every hour, and the forecast is used to set the upper economic limit on these bids, such that the resource is not dispatched above its forecasted capability in any interval. Therefore, the maximum MWs dispatched by the CAISO for a VER could be at, above, or below the net qualifying capacity value depending on the resource’s forecasted output. Wind and solar resources are exempt from RAAIM penalties for generic (local and system) resource adequacy.

Because the local regulatory authority should adopt an ELCC methodology for determining the qualifying capacity for demand response, the CAISO is considering here how to accommodate variable-output demand response resources in the CAISO market similar to VERs, in which the DR resource would fulfill its must offer obligation by bidding to its capability.

The CAISO considered two options for the type of real-time data submission required to enable these resources to bid to their capability. The first option would be for resources that can reasonably forecast their output by T-75 minutes, when bids are due in the real-time market. These resources can reflect their capability through their bids into the day-ahead and real-time markets. The CAISO has received feedback from stakeholders that implies many demand response resources do not have intra-hour variability that would require more granular data submission to ensure feasible dispatches. In this case, it seems unnecessary for resources to provide real-time data after T-75 to reflect their capability. Instead, resources could reflect their capability through their bids, which are submitted on an hourly basis 75 minutes prior to the operating interval for the real-time market.

The second option would require resources to submit their forecasted capability in real-time on a 15- or 5-minute basis to reflect any updates to real-time capability after bid submission. This way, resources could still submit bids 75-minutes prior to the operating interval, as is done today. Then, if their capability changes between when they submit their bids and the operating interval, the most recent forecast would set the upper economic limit on the resource’s bids and the amount the resource could be dispatched. This option would be required if resources experience intra-hour variability in order to ensure feasible dispatches that do not exceed the resource’s capability. Because demand response resource performance is largely dependent on consumer behavior, the CAISO does not have the appropriate visibility into individual resource capabilities to forecast load reduction for these resources.

The CAISO received stakeholder feedback on these two options and based on stakeholder input, the CAISO believes it is appropriate to allow variable output DR to reflect variability through their bids, which are submitted every hour, rather than more frequent data submission of resource availability, such as every 15 or 5 minutes. Several stakeholders have indicated to the CAISO that more frequently updated availability is likely not needed for the current demand response programs participating in the CAISO market, and that their availability can be reflected under the existing timeline for bid submission (hourly at T-75) . Additionally, some stakeholders indicated that requiring resources to have more stringent data submission requirements would likely be cost prohibitive, without providing additional benefits. Given this, the CAISO is willing to allow resources to bid their availability given resource availability will not change throughout the course of the hour. If capabilities of demand response programs or grid needs shift in the future, the CAISO could revisit this requirement.

Additionally, because the CAISO proposes the scheduling coordinator for the resource would submit bids reflective of the resource's capability, as determined by the demand response provider, to fulfill its must offer obligation, it is important to establish adequate controls to limit opportunities to submit inaccurate bids for strategic purposes. The CAISO is considering ways to eliminate any incentives for submitting bids that do not accurately reflect availability. These could include auditing provisions, testing procedures, and performance penalties. The CAISO welcomes stakeholder feedback on such controls that should be put in place.

The must offer obligation for variable-output demand response would not require the resource to bid up to the shown capacity value but rather to its capability. The capability of the resource could be at, above, or below the shown capacity value specified in the supply plan. Under this proposal, the CAISO would exempt variable-output demand response that bids its availability from RAAIM, similar to wind and solar.

The CAISO has introduced proposals in Resource Adequacy Enhancements and Day-Ahead Market Enhancements initiatives modifying offer obligations to align with the new products proposed in the Day-Ahead Market Enhancements.[26, 27] In those initiatives, the CAISO is proposing day-ahead must offer obligations for all RA resources and real-time must offer obligations for all resources with day-ahead awards.

In this ESDER proposal, the CAISO proposes to align the must offer obligation for proxy demand resources and reliability demand response resources with the RA Enhancements and Day-Ahead Market Enhancements proposals. The CAISO proposes variable-output proxy demand resources bid to their full capability in the day-ahead market in all hours it is available and for all products it is eligible for and required to provide. Like other resources, its real-time must offer obligation will be based on day-ahead market awards. For example, if a DR resource receives a day-ahead market award in hour ending 17, 18, and 19, the resource must provide energy bids up to its day-ahead award in those hours in real-time. If a resource cannot submit bids up to its full day-ahead award in real-time due to changes in load reduction capability from day-ahead to real-time, no pay provisions may apply.

Due to the unique purpose of reliability demand response resources as a reliability resource called on after the CAISO declares a warning or emergency, the CAISO proposes reliability demand response resources continue to have the option to bid into day-ahead. Reliability demand response would then be required under a must offer

[26] For a detailed description of must offer obligations for RA resources, see the RA Enhancements stakeholder initiative webpage: http://www.caiso.com/StakeholderProcesses/Resource-Adequacy-Enhancements

[27] For a detailed description of proposed new products and eligibility requirements and the real-time must offer obligation, see the Day-Ahead Market Enhancements stakeholder initiative webpage: http://www.caiso.com/StakeholderProcesses/Day-ahead-market-enhancements

obligation to bid its full capability in real-time regardless of whether or not it receives a day-ahead award.

If a resource does not have variable-output and can provide consistent load reduction throughout the RA month and year, the CAISO proposes the resource bid its full shown RA value into the day-ahead market, consistent with the standard 24 by 7 must offer obligation proposed in RA Enhancements. If the resource received a day-ahead award, the resource must bid that capacity into the real-time market.

7 Next Steps

The CAISO will hold a stakeholder meeting on March 2 and 3, 2020 to review the second revised straw proposal and encourages stakeholders to submit comments by March 16, 2020.

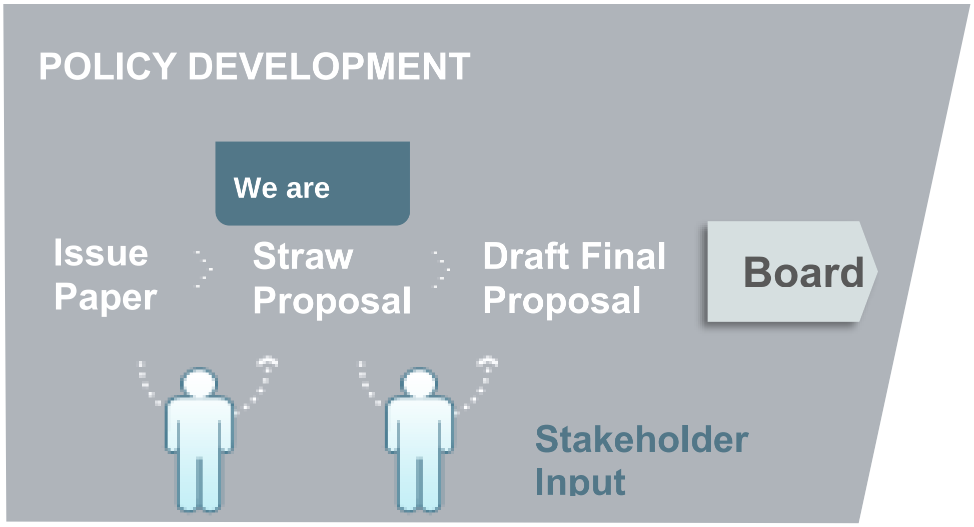
At the March 3 stakeholder meeting the CAISO will introduce ideas concerning a minimum charge parameter for storage resources, within the ESDER4 initiative, which has previously been proposed and presented as part of the Resource Adequacy Enhancement initiative. This topic touches on the operationalization of resources to ensure reliability in the real-time market. Stakeholder comments from the Resource Adequacy Enhancement initiative suggest that the topic be presented to the stakeholders following the ESDER4 initiative to gain additional comment on how the topic may be further vetted to ensure the target audience most impacted by the proposal is informed.

8 Stakeholder Process

The CAISO remains at the “Straw Proposal” stage in the ESDER 4 stakeholder process with the publication of this Second Revised Straw Proposal. Figure 14 below shows the positioning of the straw proposal process within the overall ESDER 4 stakeholder initiative.

The purpose of the straw proposal process is to present the scope and further enhance proposed solutions of identified issues related to the integration, modeling, and participation of energy storage and DERs in the CAISO’s market. The CAISO continues to review and incorporate stakeholder feedback received through comments and working group meetings to evaluate and enhance proposals the CAISO develops through this initiative. After publication of the Second Revised Straw Proposal, the CAISO will hold working group meetings to inform stakeholders and refine development of in-scope proposals. As appropriate, the CAISO may organize focused working groups to address complex issues or those elements that have cross-jurisdictional concerns as we move through the initiative process.

Figure 14: Stakeholder Process for ESDER 4 Stakeholder Initiative



9 Energy Imbalance Market Classification

CAISO staff believes that ESDER 4 involves the Energy Imbalance Market (EIM) Governing Body's advisory role to the Board of Governors (Governing Body – E2 classification). This initiative proposes changes to the non-generator resource and proxy demand resource model, with the aim of reducing barriers to participation and enhancing the ability to provide services in the day-ahead and real-time markets. While proposed enhancements will be applicable to EIM participants, there are no changes specific to EIM balancing authority areas.

All of the new proposed features would apply generally throughout the ISO market, and thus be advisory for the EIM Governing Body.

10 Appendix

Cycling cost modelling (from the Revised Straw Proposal)

Material provided in this appendix includes the proposal that was outlined in the revised straw proposal, as a reference.

To date, the CAISO focused primarily on potential models for cycling costs because they represent the most complex component of marginal costs for storage resources. In this proposal, the CAISO outlines two methodologies to account for cycling costs based on academic research by Bolun et al. This research uses a 'rain-flow' model to account for depth of discharge, the primary contributor to storage cycling costs.[28]

Cycling costs are particularly relevant for lithium-ion batteries, and this methodology captures the idea that 'deeper' discharges may be more expensive than shallow discharges. As discussed above, as a storage resource charges and discharges, the metal that physically makes up the battery degrades. As this happens, the battery becomes less effective at holding charge, and eventually will be unable to meet CAISO interconnection specifications required for the resource. This will necessitate that the owner upgrade the storage resource so that it can meet its obligations. The research shows that degradation occurs faster when resources are discharged from very high states of charge to very low states of charge, compared to operating within a narrow band for state-of-charge, even when delivering identical quantities of energy (MWh) to the grid.

Example: Depth of Discharge Costs

Depth of discharge costs refers to the costs incurred from cell degradation when a storage resource discharges energy from an initial state-of-charge to another final state-of-charge. This example illustrates that total costs associated with depth of discharge may be quadratic, is incurred over large spans of time, and that a single calculation for depth of discharge may be dis-aggregated by other discharge periods.

This example presents a hypothetical storage resource that has a straightforward quadratic relationship between depth of discharge and total cost. Total costs associated with specific discharge of a certain depth are outlined in Table 1. The table shows that discharging the resource by 10% will only cost $1, while discharging the resource by 20% will cost $4. As the total depth of discharge increases, the total costs associated with that discharge also increases in a quadratic fashion.

Because total cost increases at a quadratic rate, the marginal cost increases linearly with the total depth of discharge. For example, the additional cost incurred from discharging just 10% of the total state-of-charge to 20% of the state-of-charge incurs an additional $3 of total cost. Therefore, total costs rise from $1 to $4. A discharge of 20% of the total state-of-charge to 30% will incur an additional cost of $5, increasing the total from $4 to $9.

[28] "Factoring the Cycle Aging Cost of Batteries Participating in Electricity Markets," Bolun, et al. https://arxiv.org/pdf/1707.04567.pdf.

Table 1: Costs associated with specific cycle depths

Cycle Cepth (CD)	Total Cost ($)	Marginal Cost ($)
10%	1	1
20%	4	3
30%	9	5
40%	16	7
50%	25	9
60%	36	11
70%	49	13

A numerical example with a resource and accompanying hourly energy schedules is outlined in Table 2. In this example, suppose a hypothetical resource is capable of storing and releasing up to 10 MWh of energy, and the resource is initially charged at 7 MWh (or at 70% state-of-charge). The resource then discharges from 7 MWh (70%) down to 3 MWh (30%) and the associated total cost is $16. As expressed above, the dependency for determining costs is not on the time that the discharge occurs, but the quantity of discharge in energy or change in state-of-charge. On the left side of Table 2, the discharge from 7 MWh to 3 MWh occurs in a single hour. In hour 2, the resource is scheduled to discharge 4 MW, but is not scheduled to discharge at any other time in the day. The right hand side of Table 2 shows an example where the discharge is spread over a 4-hour period, in hours 2 through 5. During each of these hours, the resource is scheduled to discharge at 1 MW. Table 2 illustrates the total costs and the marginal costs for both discharges. Notice, on the right hand side, that each successive hour that the resource is dispatched, the cost to operate increases.

Table 2: Marginal Costs for different dispatches

Hour	P (MW)	SOC (MWh)	SOC (%)	Cost		Hour	P (MW)	SOC (MWh)	SOC (%)	Cost
1	0	7	70%	0		1	0	7	70%	0
2	4	3	30%	16		2	1	6	60%	1
3	0	3	30%	0		3	1	5	50%	3
4	0	3	30%	0		4	1	4	40%	5
5	0	3	30%	0		5	1	3	30%	7
6	0	3	30%	0		6	0	3	30%	0
				16						16

Bolun goes on to illustrate that when charging and discharging at multiple intervals, the cost calculation approach “resets” when the resource begins to charge. For example, if the same example resource used above, discharges from 7 MWh to 3 MWh, then charges from 3 MWh to 5 MWh, then discharges from 5MWh to 1 MWh, the costs associated with the two discharges are equal to a single 6 MWh discharge plus a single 2 MWh discharge. The costs are not equal to two separate 4 MWh discharges. These costs are illustrated in Table 3. Note that the marginal costs accrued in hours 5 and 6 correspond to a 50% and 60% discharge, rather than a 30% and 40% discharge from Table 1.

Table 3: Multiple charge and discharge periods

Hour	P (MW)	SOC (MWh)	SOC (%)	Cost ($)
1	0	7	70%	0
2	4	3	30%	16
3	-2	5	50%	0
4	2	3	30%	4
5	1	2	20%	9
6	1	1	10%	11
				40

The Model

Based on the information above, the CAISO is proposing two options for modeling cycle costs. These models are illustrated by examples of how depth of discharge might contribute to total costs and marginal costs for a storage resource.

1. Total Depth of Discharge Model

This model assumes costs at the resource's maximum cycle depth and it increases as the state-of-charge decreases. The model's assumptions align with the concept of increasing marginal costs with lower state-of-charge values but may overestimate the cost for storage resources to discharge.

Equation 4: Total Depth of Discharge

$$\mathrm{CD}_{i,t} = \mathrm{v}_{i,t}\, \rho_i \left(\mathrm{Max\ SOC} - \mathrm{SOC}_{i,t}\right)$$

where:

v:	Value equal to 1 when the state-of-charge is decreasing
ρ:	Cell degradation cost (Constant)
Max SOC:	Maximum SOC available for dispatch (generally 100%)[29]
SOC:	State-of-charge

[29] Resources may not be able to offer the full state-of-charge into the market for a variety of reasons. Resources operating at the extreme values for state-of-charge may experience extreme cell degradation, in excess of the cell degradation modelled in this paper. Resources' scheduling coordinators submit maximum storage capability to the ISO and this value is stored in Master File. Energy storage values for these resources are used to determine a value that these resources may qualify for in the resource adequacy construct. Some resource owners may "oversize" storage project so that modelling state-of-charge energy values equal to 100% are at levels where the physical resource is actual capable of storing additional capacity, but it is not available to the market. This may also be the case for state-of-charge values close to 0%, where the resource may be physically capable of discharging more energy, but the energy is not available to the market.

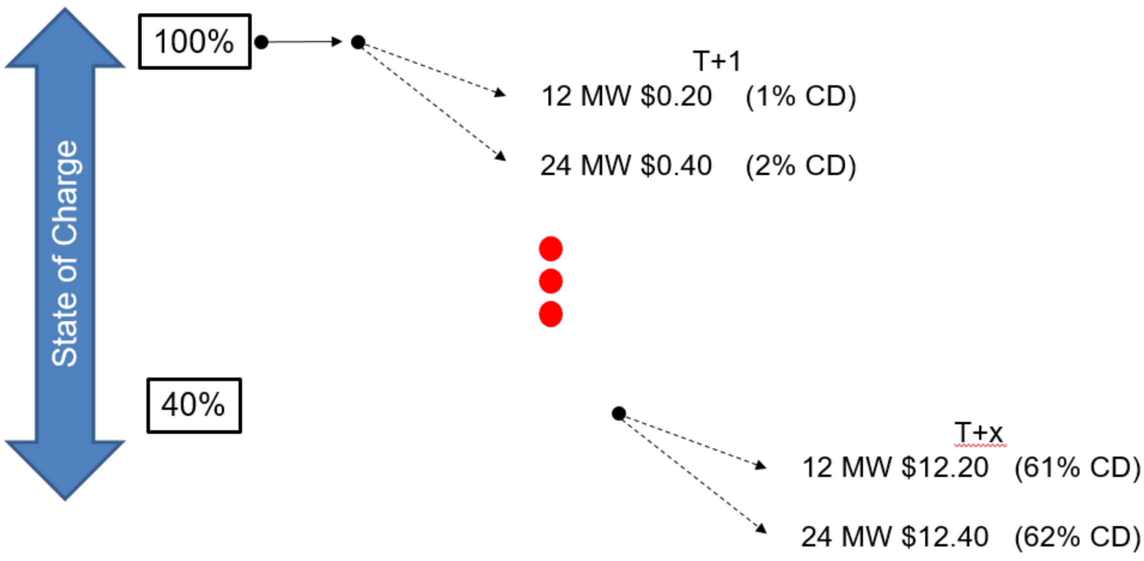
i: Resource
t: Interval

To illustrate this approach, assume there is a hypothetical storage resource capable of generating in the range between -24 MW (charging) to 24 MW (discharging), and the resource is capable of storing up to 100 MWh of energy. Suppose further that the resource operator determined that the cost for cell degradation is $20/MWh, which will be used for the value of ρ.

The total depth of discharge approach is a model where cycling costs are calculated dynamically, and are directly related to the state-of-charge for the resource at the day-ahead or real-time interval when the default energy bid is being calculated. The costs to discharge will increase as the state-of-charge value decreases.

Figure 15 shows the relationship between state-of-charge and total cost for discharge, as illustrated in Equation 4. In this example, when the resource is fully charged, at 100% state-of-charge, the cost to discharge would only be $0.20 for 12 MW or $0.40 for 24 MW, or a linear function including those values between 0 MW and 24 MW. At a later point in time, when the state-of-charge is lower at 40%, the cost to discharge increases to $12.20 for 12 MW or $12.40 for 24 MW. Each successive discharge, corresponding to lower total state-of-charges, corresponds to increasing costs for discharge.

Figure 15: Example of total depth of discharge approach



2. Individual Depth of Discharge Model

This model assumes maximum costs of cycle depth per dispatch during every interval. Costs are determined independently during each interval and are only based on how much the total amount of (MW) dispatch, regardless of prior dispatches and current state-of-charge. The model may overestimate costs for large dispatches when cycle depth is thin and underestimate costs for shallow dispatches when cycle depth is deep. This methodology may align more with the notion that a resource will incur costs any time the battery is discharging, and will generally not be incurring costs when the battery is idle.

Equation 5: Individual Depth of Discharge

$$\mathrm{CD_{i,t}} = \mathrm{v_{i,t}}\,\rho_\mathrm{i}\left(\mathrm{SOC_{i,t-1}} - \mathrm{SOC_{i,t}}\right)$$
$$= \mathrm{v_{i,t}}\,\rho_\mathrm{i} * \frac{\mathrm{P_{i,t-1}} + \mathrm{P_{i,t}}}{2} * \Delta t$$

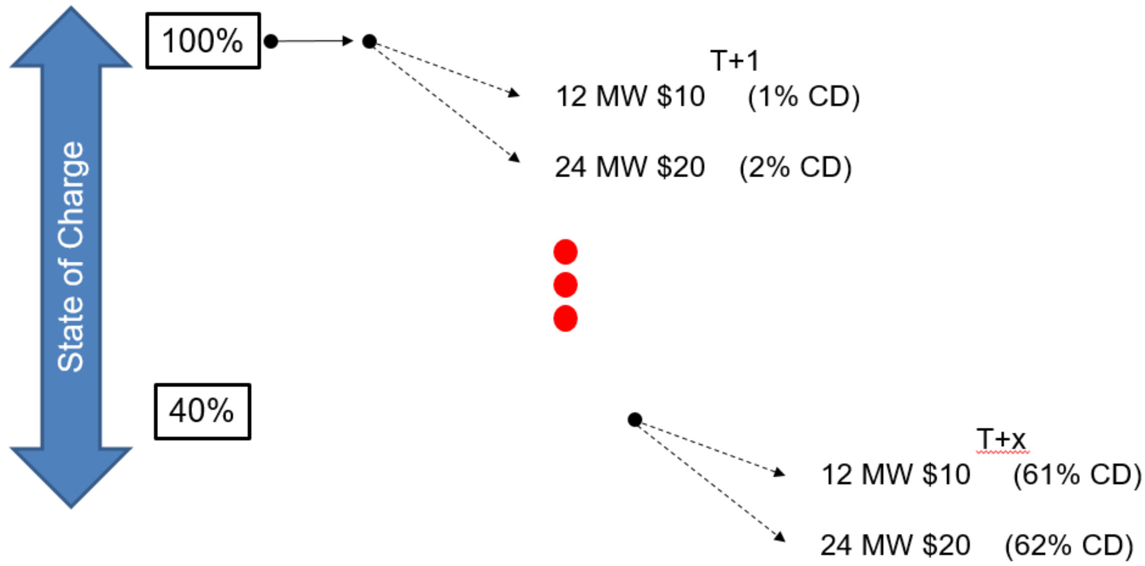
where:

v:	Value equal to 1 when the state-of-charge is decreasing
ρ:	Cell degradation cost (constant)
SOC:	State-of-charge
P:	Dispatch instruction (Market decision variable)
Δt:	Fraction of an hour (1/12 in RTD market)
i:	Resource
t:	Interval

Equation 5 can be simplified to a function that does not depend on state-of-charge, but only on dispatch instruction. The CAISO updates values for state-of-charge in the real-time market based on the average of the previous two dispatch instructions. This matches the assumption that any resource will reach a dispatch instruction in the middle of the 5-minute interval and will be ramping linearly from the previous dispatch instruction. The actual dispatch instruction from the

Also, Equation 5 is expressed as a function of ***ρ***, the resource specific value representing the cost of cell degradation related to dispatch. Although the parameter is used in Equation 4, the values take on two different meanings in each of the equations. In Equation 4 the value of ***ρ*** represents the cost of discharge that the resource would incur if the resource were to be dispatched down to 0% state-of-charge. This value would remain the same in the day-ahead and real-time markets. However, the ***ρ*** value in Equation 5 represents a multiple of the same cost, so that the values were related to the specific MW dispatch received by the resource. These values do differ between the day-ahead and real-time markets. In this case the value of ***ρ*** used in Equation 4 is divided by the maximum output of the resource (24 MW) then multiplied by the number of intervals in an hour (12 intervals each hour in the real-time market). In the example illustrated below the value of ***ρ*** is $10.

Figure 16: Example of individual depth of discharge model



In the case of the hypothetical resource used to describe the first function for cycle depth, we continue to assume that the resource may be dispatched in the range between -24 MW to +24 MW, and that the resource has 100 MWh of energy storage capability. As discussed, the pricing for the resource is agnostic to the state-of-charge, and the only factor impacting how the cost for cycling is the dispatch of the resource. Figure 16 shows that if the resource is fully charged at 100% or is only charged at 40%, the cost to discharge the hypothetical resource is linear with dispatch instructions. It also shows that the cost to discharge is equal to $20/MWh when the resource is dispatched at its maximum capability (24 MW) and is arbitrarily small when minimally dispatched.

One potential pitfall with the second model for cycling costs, is that the storage resource could be dispatched frequently at low levels of output, since the market will view these dispatches as relatively inexpensive. But the actual costs may be significantly higher if the resource is at a low state-of-charge. Similarly, the resource may not be dispatched at full output, because the model will associate this with a relatively high cost. However, it may be efficient for these resources to be dispatched close to their maximum capability if the resource is at an operation point where the cycle depth would be relatively shallow.

The first model captures costs based on total depth of discharge, while the second model captures costs that are independent of total depth of discharge. At this time, the CAISO is not proposing a specific model but continues to assess both options. Stakeholder feedback and data analysis will be used to inform future iterations for modelling costs for storage resources to discharge.