Flexible Ramping Products

Second Revised Straw Proposal

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1. INTRODUCTION

This paper will describe the ISO's proposal to define the upward and downward flexible ramping products. The purpose of this stakeholder effort is to develop market-based flexible ramping products to address the operational needs in real-time market facing the upcoming challenges from increasing renewable penetration. Prior to these market-based full flexible ramping products, the ISO has proposed to implement a flexible ramping constraint to address certain reliability and operational issues observed in the ISO's operation of the grid.[1] Upon the completion of the Flexible Ramping Constraint stakeholder process, the ISO recognized that greater market effectiveness can be gained by developing market-based products that allow for the identification, commoditization and compensation for the needed flexible capability. The ISO has observed that the unit commitment and position of units in the real-time pre-dispatch process (RTPD), also known as the real-time unit commitment process, sometimes lack sufficient ramping capability and flexibility to meet conditions in the five-minute real-time dispatch (RTD) during which conditions may have changed from the assumptions made during the prior pre-dispatch. For example, the insufficient ramping capability sometimes manifests itself in triggering power balance violations, which means the there is no feasible system wide RTD schedule to maintain supply and demand power balance. In this case, the system has to rely on regulation services to resolve the issue in real delivery time after the imbalance has caused frequency deviation or area control error (ACE), which is undesirable outcome. If there is insufficient regulation service, the result of insufficient ramping capability may result in leaning on interconnection. In addition, when power balance is violated, the RTD energy price is not priced by economic bids, but by administrative penalty prices, which may impact market efficiency in the long run.

The flexible ramping products to be developed in this stakeholder process will help the system to maintain healthy ramping capability. The flexible ramping products specifically target the imbalance differences that arise between the RTPD and RTD, which are 5-minute variability and uncertainties from the RTPD point of view. The term "variability and uncertainties" is used in the ISO's 20% renewable portfolio standard study in the context of load following requirements.[2]

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[1] See CAISO Technical Bulletin "Flexible Ramping Constraint" for detailed discussion of the constraint, http://www.caiso.com/Documents/TechnicalBulletin-FlexibleRampingConstraint_UpdatedApr19_2011.pdf, February 2011. See California ISO Tariff Amendment Proposing the Flexible Ramping Constraint and Related Compensation: http://www.caiso.com/Documents/2011-10-07_FlexiRampConstraint_Amend.pdf

[2] CAISO, Integration of Renewable Resources, http://www.caiso.com/2804/2804d036401f0.pdf

Specifically, the variability may come from market granularity differences in load profile, variable energy resource supply. In addition variability may also arise due to unit startup/shut down profile, multi-stage generator transition profile, and inter-tie schedule inter-hour ramping profile. The uncertainties may include everything that has a random nature, such as load forecast error, variable energy resources' forecast error, and other uninstructed deviations. We use the same term to make connections with the ISO's previous study from a conceptual level, and will clarify the differences between flexible ramping products and load following later in the proposal. The 5-minute variability and uncertainties are realized in the RTD, and the RTD will economically dispatch resources including deploying procured flexible ramping capabilities accordingly. Market participants will be allowed to offer ramping capabilities into the market, and the ISO will optimize such offers to economically meet the anticipated 5-minute variability and uncertainties. In order to better demonstrate the purpose and characteristics of the flexible ramping products to be developed in this process, this document includes a discussion of prospective products in the context of the existing processes and ancillary services products.

As a balancing authority, the ISO maintains power balance in real-time operations. Due to the complexity of modern power systems and electricity markets, the task of maintaining power balance is handled in a hierarchy of different time frames. The ISO operates the day-ahead market and performs residual unit commitment on the day prior to the actual operating day as the first attempt to establish balanced supply and demand schedules, commit resources adequately, and procure ancillary services. In the actual operating day, as illustrated in Figure 1, the ISO employ several real-time processes to commit resources adequately, dispatch them economically, procure additional ancillary services for system reliability, and deploy them when they are needed. The supply and demand condition at the actual delivery time may have been impacted by the decisions made in the following processes before the actual delivery time.

From about 5 hours to 15 minutes ahead of the actual delivery time, the RTPD processes perform unit commitments every 15 minutes on a 15-minute interval basis, and procure ancillary services (on top of day-ahead and hour-ahead procurements) for the coming 15 minutes.

About 5 minutes ahead of the actual delivery time, the RTD performs economic dispatches every 5 minutes on a 5-minute interval basis.

If a major contingency happens, the operator may choose to perform a special process, the real-time contingency dispatch (RTCD), to economically deploy operating reserves (spinning reserve and non-spinning reserve) in order to restore the system back to normal operating conditions. RTCD performs both unit commitments and dispatches on a 10-minute interval basis.

At the actual delivery time, a system imbalance will manifest itself in system frequency, inadvertent transfers between other balancing authority areas or Area Control Error (ACE), and will trigger the utilization of automatic generation control on resources that are awarded regulation services in day-ahead for the corresponding hour or in RTPD for the corresponding 15-minute interval.

Electricity is different from other commodities in that it is produced and consumed instantaneously, and both supply and demand are constantly changing. These properties pose a great challenge to the ISO to maintain power balance every minute and every second. That is why it is necessary to have temporal hierarchical processes to look ahead at future supply and demand conditions, and reserve dispatchable capacities as ancillary services. Currently, the look-ahead is performed in a deterministic way to balance expected supply and expected demand in the future.

Assuming the load forecast and resource schedules are close to their expected values, this approach should work well. The electric power industry has been operated in this way for a long time. However, with the increased amount of variable energy resources, whose actual outputs may vary, and cannot be accurately forecasted, looking ahead at expected values may not be sufficient to maintain power balance in RTD, a reliability concern. In order to operate the grid reliably, the ISO proposes to define the flexible ramping products, which provides a market mechanism for procuring sufficient ramping capability to handle certain variability and uncertainties.

As illustrated in Figure 1, variability and uncertainties are classified into two categories according to the time they are realized. The market clearing granularity difference between RTPD and RTD results in 5-minute variability to be realized in RTD. In addition, certain uncertainties are also realized after RTPD and before RTD. These post RTPD uncertainties include load forecast changes, variable energy resources production changes, uninstructed deviations, and forced outages. The post RTPD variability and uncertainties are realized before the RTD dispatches, so RTD dispatches can "recourse"[3] according to the realizations. Approaching actual delivery time after the RTD run, the difference between actual supply/demand outputs and RTD supply/demand schedules results in post RTD variability and uncertainties. This real-time variability is caused by using the 5-minute granularity in RTD to approximate continuous output in real-time. These post RTD uncertainties include deviations of actual load from RTD load forecast, uninstructed deviations, small outages which happen in real-time, and so on. Because RTD is the last opportunity for sending out dispatches under normal operating conditions, the post RTD uncertainties once realized will only be handled by automatic generation controls (AGC), which are procured in day-ahead or corresponding RTPD as regulation services. The difference between the two categories of variability and uncertainties and how to address them are illustrated in Figure 2.

[3] "Recourse function" is a terminology in stochastic optimization, which specifies how to adapt to the realized uncertainties.

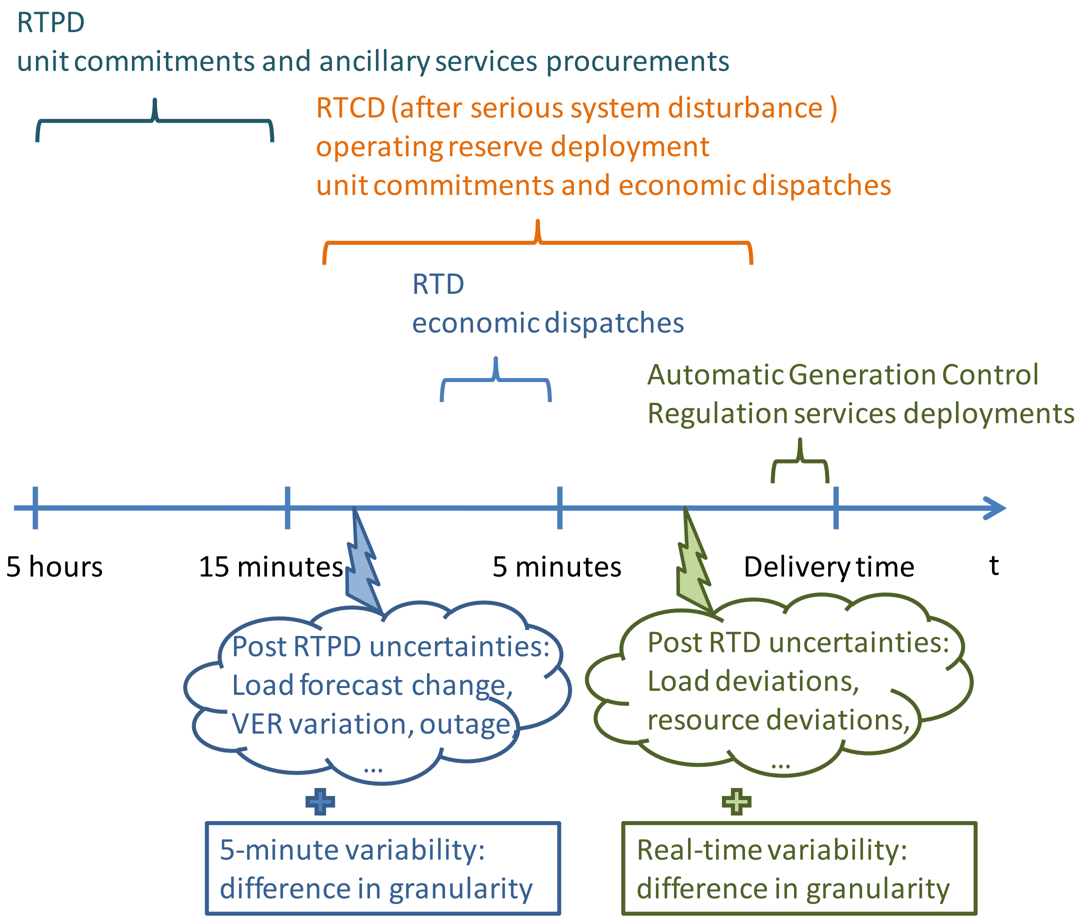

FIGURE 1: REAL-TIME MARKETS TIME FRAME

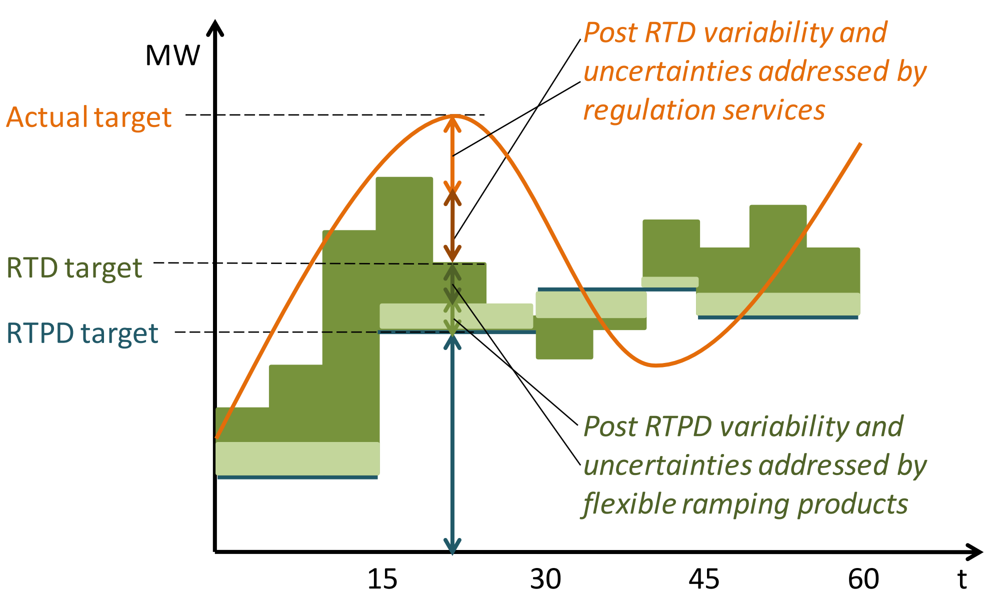

FIGURE 2: HANDLING VARIABILITY AND UNCERTAINTIES WITH FLEXIBLE RAMPING PRODUCTS AND REGULATION SERVICES

The objective of the flexible ramp product is to ensure sufficient flexibility is committed in RTPD with high confidence anticipating imbalance differences can be realized in RTD, and to maintain and utilize such flexibility in response to the imbalance differences on a continuous 5-minute interval basis. Such differences can arise due to load and supply variability and uncertainties. Variability can be expressed as the difference between hourly (load following) or 15 minute (flexible ramp) average net load and 5 minute average net load. Uncertainties can be expressed as the differences expected net load and the expected net load plus forecast error. Flexible ramping product is similar to load following referred to in renewable integration planning studies except that the load following variability component is based on the difference between hourly average net load and the 5 minute average net load levels accounting for uncertainties while the flexible ramp product variability component is based on the difference between 15 minute average net load and 5 minute average net load. In an operational timeframe that has a 15-minute unit commitment process such as RTPD, it is appropriate to consider the flexible ramp product quantifying the difference between net load in RTPD 15-minute interval and the 5-minute interval. For a particular interval, the difference between load following requirement and flexible ramp requirement is addressed by the RTPD commitment. The following conceptual relationships attempt to illustrate the relationship of load following and flexible ramp product and their associated contributions.

$\text{Load Following Up} = \text{Variability}_{\text{up-hourly}} + \text{Uncertainty}_{\text{up}} \approx \text{Flexible RampUp}_{15\text{min}} + \text{RTPDUp}_{15\text{min}}$

where

$\text{Variability}_{\text{up-hourly}} = \max(\text{NetLoad}_{5\text{min}} - \text{NetLoad}_{\text{hourly}})$

$\text{Uncertainty}_{\text{up}} = \text{NetLoad}_{\text{expected+forecast error}} - \text{NetLoad}_{\text{expected}}$

$\text{RTPDUP}_{15\text{min}} = \max(\text{NetLoad}_{15\text{min}} - \text{NetLoad}_{\text{hourly}})$

$\text{Flexible RampUp}_{15\text{min}} = \max(\text{NetLoad}_{\text{5min expected + forecast error}} - \text{NetLoad}_{\text{15 expected}})$

and

$\text{Load Following Dn} = \text{Variability}_{\text{dn-hourly}} + \text{Uncertainty}_{\text{dn}} \approx \text{Flexible RampDn}_{15\text{min}} + \text{RTPDDn}_{15\text{min}}$

where

$\text{Variability}_{\text{dn-hourly}} = \max(\text{NetLoad}_{\text{hourly}} - \text{NetLoad}_{5\text{min}})$

$\text{Uncertainty}_{\text{dn}} = \text{NetLoad}_{\text{expected}} - \text{NetLoad}_{\text{expected-forecast error}}$

$\text{RTPDDn}_{15\text{min}} = \max(\text{NetLoad}_{\text{hourly}} - \text{NetLoad}_{15\text{min}})$

$\text{Flexible RampDn}_{15\text{min}} = \max(\text{NetLoad}_{\text{15expected}} - \text{NetLoad}_{\text{5min expected- forecast error}})$

Figure 3a and 3b attempt to graphically illustrate how flexible ramp and load following are determined using the forecast net load.

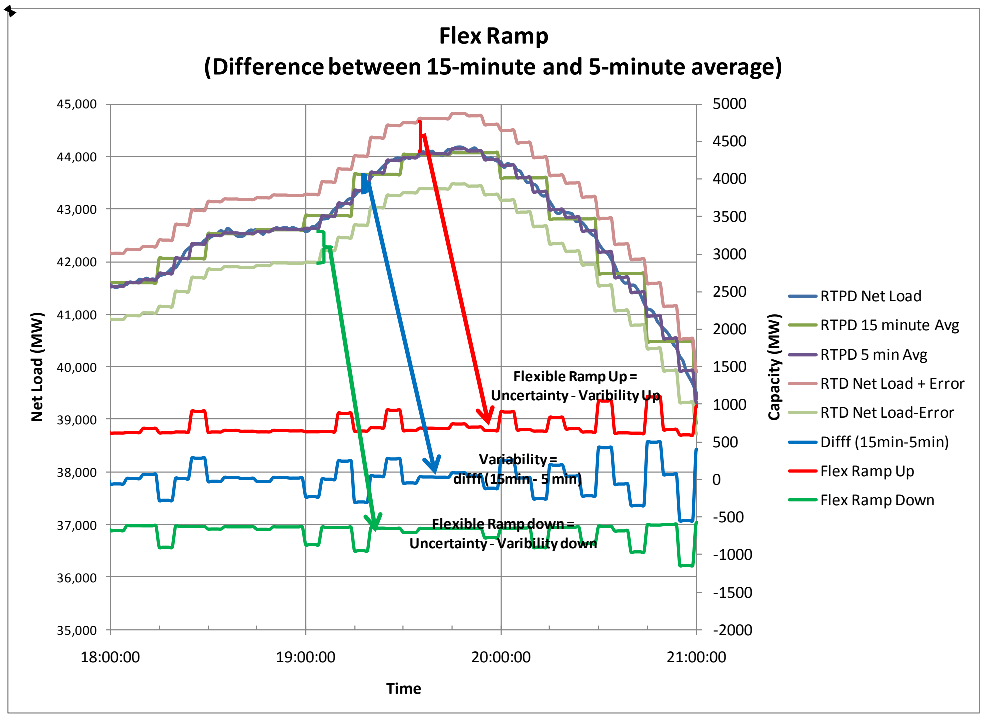

Figure 3a: Flexible Ramp Product Illustration

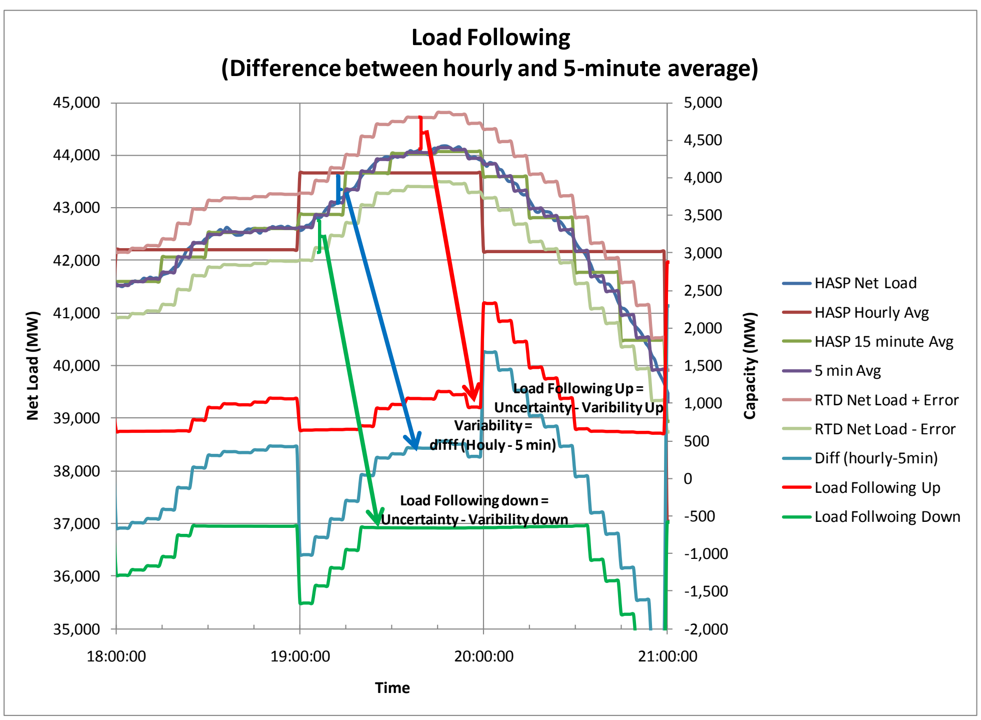

Figure 3b: Load Following Illustration

The flexible ramping products are targeted at handling the post RTPD variability and uncertainties, which is the imbalance difference of supply and demand between RTPD and RTD. The ISO intends to first procure the flexible ramping products partially (e.g. with 60% confidence level) in day-ahead market, and then procure additional flexible ramping products in RTD to achieve higher confidence level (e.g. 95% confidence) in handling the imbalance differences. In addition, RTPD is used as an important instrument to create flexible ramping headroom such that the RTD procurement target can be feasible. Flexible ramping products requirements in both day-ahead market and RTPD will be based on anticipated variability and uncertainties between RTPD and RTD. The ISO will perform statistical study using historical data to determine the requirements. In the day-ahead market, the ISO intends to procure the portion for of flexible ramp that has a high confidence of being used and will procure the remainder of the flexible ramp product in RTPD.

The changes in the second revised straw proposal in response to stakeholders' comments include:

- procuring real-time flexible ramping capability in RTD
- a resource bidding for energy will be assumed to have a zero $/MWh bid for providing flexible ramping if the resource does not explicitly bid for flexible ramping
- a more thorough example that covers day-ahead and real-time settlements
- cost allocation excluding metered subsystems that self manages variability and uncertainty.

2. FLEXIBLE RAMPING PRODUCTS DESIGN

The flexible ramping products are designed to deal with the imbalance differences between the RTPD and the RTD. The differences can result from variability or uncertainties. From a stochastic programming point of view, faced with the variability and uncertainties, a stochastic program will commit and dispatch units differently than without those variability and uncertainties considered, such as committing more flexible units, positioning units at faster ramping dispatch levels in anticipation of imbalance changes in RTD. The current technology does not allow detailed modeling of those variability and uncertainties and solving stochastic programs in real-time. Therefore, the flexible ramping products are created as a heuristic way to mimic what a stochastic program would do to deal with those variability and uncertainties. In other words, the flexible ramping products will be able to commit fast ramping units, and position units at fast ramping dispatch levels. The flexible ramping products awards will be compensated according to the marginal prices in the procurement processes (day-ahead market and RTD). RTPD is used as an instrument to create flexible ramping headroom such that RTD has sufficient ramping flexibility to be procured. However, the resources that provide flexible ramping headroom in RTPD will not be financially binding. RTD will re-evaluate the ramping requirement and re-procure flexible ramping products. The RTD flexible ramping procurements are financially binding, and will be paid the RTD marginal prices.

Because RTD is on a 5-minute interval basis, the flexible ramping products are also a 5-minute ramping products[4] meaning that the flexible ramping product award is limited by how much a resource can ramp within 5 minutes. This is to ensure that the procured flexible ramping products can be fully deployed in one RTD interval when they are needed.

The flexible ramping consists of separate products in the upward and downward direction. The market will accept bids on both products, which express the resources' cost to provide flexible ramping. Similar to ancillary services, a flexible ramping bid will only have one bid segment. The upward bid can be different from the downward bid. Every resource that has an economic energy bid, and is dispatchable by the ISO, can provide flexible ramping regardless whether the resource submits an explicit flexible ramping bid or not. If a resource does not have an explicit flexible ramping bid, it is assumed to have zero cost to provide flexible ramping.

There is no explicit self provision mechanism for flexible ramping. A Scheduling Coordinator can bid zero or simply not bid for the amount of flexible ramping it wants to self provide. If the SC is fully awarded flexible ramping, then it effectively hedges its obligation with the payment received. If the SC is not fully awarded flexible ramping (even with bid price zero $/MWh), it implies the marginal price of flexible ramping must be zero $/MWh, so there will be zero cost allocation. In either case, an SC can hedge its cost allocation obligation effectively, so there is no need for an explicit flexible ramping self provision mechanism.

2.1 COOPTIMIZING FLEXIBLE RAMPING PRODUCTS WITH ENERGY AND ANCILLARY SERVICES IN DAY-AHEAD MARKET

[4] The flexible ramping products are procured in the day-ahead market on an hourly basis, and in RTD on 5-minute interval basis. In RTPD, flexible ramping headroom is created on a 15-minute interval basis, but it is not a binding procurement.

This section will cover the stylized optimization model of co-optimizing the flexible ramping products with energy and ancillary services in the day-ahead market. The interplay between day-ahead market and RTPD will be discussed in section 2.2.

The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[5] The meanings of the variables used in this section are explained in Appendix A. We will discuss the changes to the objective function and constraints on top of Wu and Rothleder's model due to the addition of the flexible ramping products. The detailed equations are presented in Appendix B.

The change to the objective function is to add the bid costs from the flexible ramping products.

The changes to the constraints involving flexible ramping are as follows.

Five-minute upward flexible ramping capability limit This constraint ensures that a resource's upward flexible ramping product award does not exceed what it can ramp in 5 minutes.

Five-minute downward flexible ramping capability limit This constraint ensure that a resource's downward flexible ramping product award does not exceed what it can ramp in 5 minutes.

Ten-minute upward ancillary service and flexible ramping limit This constraint ensures the total amount of upward reserves (regulation-up, spinning, and non-spinning) awards and the upward flexible ramp product award does not exceed what the resource can ramp in 10 minutes.

Ten-minute downward ancillary service and flexible ramping limit This constraint ensures the total amount of regulation-down award and downward flexible ramping product award does not exceed what the resource can ramp in 10 minutes.

Upward ramping sharing[6] This constraint limits the extent to which the awards of regulation-up, spinning reserve, non-spinning reserve and upward flexible ramping product can share the resource's ramping capability with the ramp used to support the changes in energy.

Downward ramping sharing[6] This constraint limits the extent to which the awards of regulation-down and downward flexible ramping product can share the resource's ramping capability with the ramp used to support the changes in energy.

Active power maximum limit This constraint limits the amount of the awards of energy schedule, upward reserves and upward flexible ramping product to be less than or equal to the resource's maximum operating capability.

Active power minimum limit This constraint limits the amount of energy schedule minus the awards of regulation-down and downward flexible ramping product to be greater than or equal to the resource's minimum operating level.

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[5] Tong Wu, Mark Rothleder, Ziad Alaywan, and Alex D. Papalexopoulos, "Pricing Energy and Ancillary Services in Integrated Market Systems by an Optimal Power Flow," *IEEE Transactions on Power Systems*, pp.339-347, 2004.

[6] See CAISO Technical Bulletin "Simplified Ramping" for details of the ramp sharing constraints and coefficients, http://www.caiso.com/2437/2437db41245c0.pdf, August 2009.

Upward flexible ramping requirement This constraint ensures that the total amount of upward flexible ramping product awards at least meets the requirement.

Downward flexible ramping requirement This constraint ensures that the total amount of downward flexible ramping product awards at least meets the requirement.

The upward flexible ramping product shadow price is λ_t^{FRU}, and the downward flexible ramping product shadow price is λ_t^{FRD}. These two shadow prices are non-negative, because increasing the requirements will make the set of feasible solutions smaller, and thus the minimum objective function value (total bid cost) tends to increase.

Note that there is neither substitution between the flexible ramping products and the regulation services, nor substitution between the flexible ramping products and the contingent operating reserves.

Just like energy requirement and ancillary services requirements, the flexible ramping products requirement constraints will be allowed to be relaxed to a certain extent at appropriate penalty prices. The ISO might use a step penalty function such that small relaxation is subject to small penalty and large relaxation is subject to large penalty price.

The flexible ramping products will be priced at the marginal values of the requirements, which equal the corresponding shadow prices.

Payment to resource *i* providing $FRU_{i,t}$ is $\lambda_t^{FRU} \cdot FRU_{i,t}$, and the total payment in interval *t* is $\lambda_t^{FRU} \cdot \sum_{i \in I_{FR}} FRU_{i,t}$.

Nominal charge could conceptually be associated with variability or uncertainty *u* that incurs flexible ramping need is $\lambda_t^{FRU} \cdot R_{u,t}^{FRU}$, and the total charge is $\lambda_t^{FRU} \cdot \sum_{u \in UU} R_{u,t}^{FRU}$. Note that the charge on variability or uncertainty *u* is a nominal charge meaning *u* would have to pay the charge under perfect cost causation scheme. It is not the real settlement charge under the current ISO's proposal, but serves the purpose of providing an economic signal to indicate that variability or uncertainty *u* should bear the flexible ramping cost. The proposed settlement charge will be discussed later in the cost allocation section.

If there is no flexible ramping scarcity, the complementary slackness holds at the optimal solution

$$\lambda_t^{FRU} \cdot \left(\sum_{u \in UU} R_{u,t}^{FRU} - \sum_{i \in I_{FR}} FRU_{i,t} \right) = 0$$

This means the ISO should be revenue neutral under normal conditions.

If there is flexible ramping scarcity of $SLK_t^{FRU} = \sum_{u \in UU} R_{u,t}^{FRU} - \sum_{i \in I_{FR}} FRU_{i,t} > 0$, then

$$\lambda_t^{FRU} \cdot \left(\sum_{u \in UU} R_{u,t}^{FRU} - \sum_{i \in I_{FR}} FRU_{i,t} \right) = \lambda_t^{FRU} \cdot SLK_t^{FRU} > 0$$

This means the ISO is revenue adequate.

The revenue adequacy and revenue neutral properties also apply to downward flexible ramping.

The day-ahead flexible ramping procurements are financially binding. The opportunity cost of providing energy will be included in the marginal prices of flexible ramping products. This is because a resource that is capacity constrained will lose the opportunity of providing energy in day-ahead market if it is more economic for it to provide flexible ramping.

2.2 INTERPLAY BETWEEN DAY-AHEAD MARKET AND RTPD

RTPD creates headroom such that RTD has sufficient fleet flexibility to economically dispatch resources and procure flexible ramping capability. Because RTPD performs unit commitment, it is the best process to create ramping headroom in real-time. The RTPD creates flexible ramping headroom by enforcing the system wide flexible ramping requirement constraints and resource level constraints similar to the day-ahead market.

Because the energy schedule is not binding in RTPD, a resource providing flexible ramping in RTPD may not lose the opportunity of providing energy in RTD. As a result, some stakeholders are concerned about the "double payment" issue of receiving energy opportunity payment in RTPD for providing flexible ramping and receiving energy payment of the energy dispatched into the flexible ramping awards. To avoid the "double payment" issue, in the second revised straw proposal, the ISO proposes not to settle flexible ramping products in RTPD. In other words, resources provide RTPD flexible ramping product headroom is not financially binding. Rather, in RTD, flexible ramping requirements will be re-evaluated on a 5-minute interval basis, and RTD flexible ramping procurements are financially binding to be paid at RTD flexible ramping marginal prices. The purpose of enforcing flexible ramping requirements in RTPD is solely to create headroom such that RTD has sufficient fleet flexibility to economically dispatch resources and procure flexible ramping capability.

RTPD creates flexible ramping headroom by a co-optimization similar to the day-ahead, and resets the flexible ramping requirement to 95% confidence level on a 15-minute interval basis. The day-ahead procured flexible ramping awards will be protected as self-provision in RTPD so that they can meet the RTPD requirement. This is consistent with how the ancillary services procured in day-ahead market are modeled in RTPD currently.

In addition, the day-ahead non-contingent reserve awards may be fully or partially converted to upward flexible ramping if the resources have economic energy bids in RTPD. The day-ahead non-contingent reserve awards are from resources who flag them as non-contingent meaning that they are willing to be dispatched for energy rather than be kept as operating reserve if condition permits. Therefore, allowing them to be converted to flexible ramping product and then potentially be dispatched to meet realized imbalance difference is consistent with their intention. On the other hand, upward flexible ramping awards may also be fully or partially converted to contingent spinning reserves if the resources are qualified to provide spinning reserve. The potential conversions are summarized in Figure 3. The non-contingent non-spinning reserve awards in day-ahead that become online in RTPD are treated the same as non-contingent spinning reserve awards, and are allowed to be fully or partially converted to contingent spinning reserve or upward flexible ramping product.

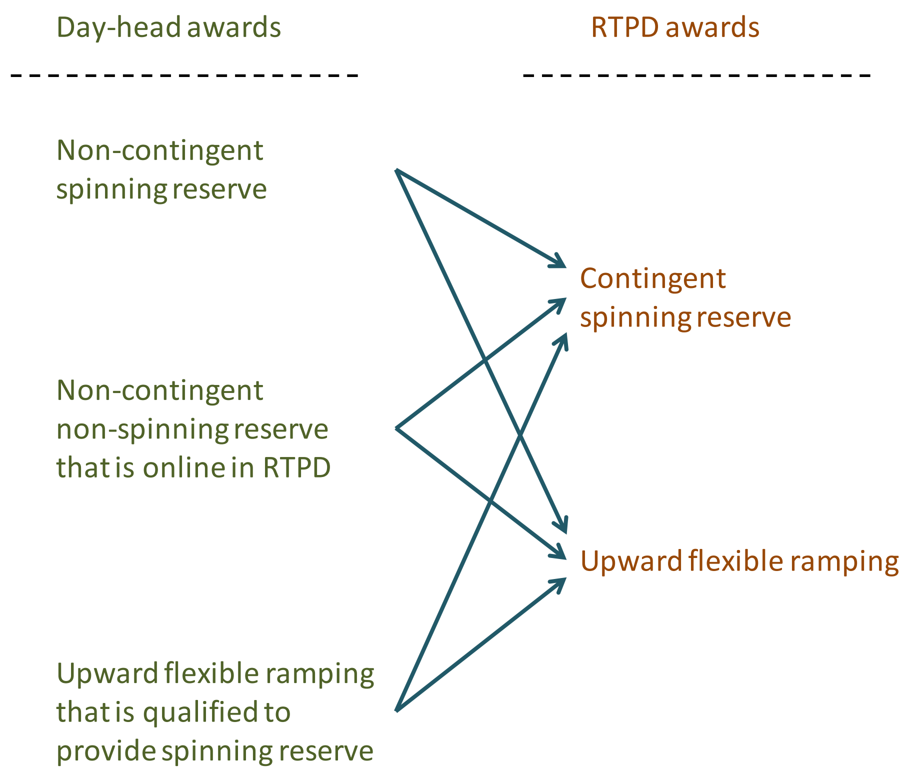

FIGURE 3: CONVERSIONS BETWEEN NON-CONTINGENT RESERVES AND UPWARD FLEXIBLE RAMPING PRODUCT IN RTPD

Allowing non-contingent reserves to be converted to upward flexible ramping product helps deal with ramping scarcity, and allowing upward flexible ramping product to be converted to spinning reserve helps deal with operating reserve scarcity. These conversions will increase the dispatch flexibility and market efficiency by allowing flexible resources to be used in the most valuable way. The conversion can only take place in RTPD, and only applies to day-ahead awards.

The conversion will only happen in the direction of lower value to higher value. For example, non-contingent spinning reserve can be converted to upward flexible ramping product only when the marginal price of upward flexible ramping is higher than or equal to the marginal price of spinning reserve in RTPD. This can be proved by contradiction. Assume the marginal price of spinning reserve is higher than the upward flexible ramping product, and at least one resource's non-contingent spinning reserve is converted to upward flexible ramping product. In this case, if the conversion is reduced by 1 MW, then the change to the objective function value is equal to the marginal price of upward flexible ramping product minus the marginal price of spinning reserve, which is negative by assumption. This means the objective function value can be improved (reduced) by reversing the conversion, and thus contradicts the optimality of the conversion. Therefore, the conversion should not have taken place. This completes the proof. Conversion from flexible ramping to spinning reserve can be proved in the same way. This also implies that the conversion can only take place in one direction for the same ancillary service region.

The ISO also allows substitution of higher quality ancillary service for lower quality ancillary service, such regulation-up for spinning reserve, and spinning reserve for non-spinning reserve. The key difference between the ancillary service substitution and the flexible ramping conversion are

- the flexible ramping conversion only converts day-ahead awards into a different product in RTPD, while the ancillary service substitution takes place in all markets that procure ancillary services including both day-ahead market and RTPD
- the ancillary services have a predetermined order of quality, but flexible ramping conversion cannot be predetermined based on higher quality or lower quality than spinning reserve and any other ancillary service,
- the order of ancillary service marginal prices is consistent with the quality order for ancillary services, while the flexible ramping marginal price does not have a predetermined relationship with the ancillary service marginal prices; the direction of conversion must be consistent with the marginal price relationship determined in the optimization.

The day-ahead awards of non-contingent spinning reserve (also non-contingent non-spinning reserve that becomes online in RTPD) and upward flexible ramping will be split into two variables, one represents the contingent spinning reserve, and the other represents the upward flexible ramping product in RTPD. The sum of these two will be less than or equal to the corresponding day-ahead award

$$FRU_{i,t} + SP_{i,t} \leq FRU_{i,t}^{DA}, \text{ for all } i \in I_t^{DA,FRU}$$

$$FRU_{i,t} + SP_{i,t} \leq SPIN_{i,t}^{DA}, \text{ for all } i \in I_t^{DA,SPIN}$$

The upward flexible ramping portion $FRU_{i,t}$ will be used to meet the upward flexible ramping requirement in RTPD, and the spinning reserve portion $SP_{i,t}$ will be used to meet the spinning reserve requirement (cascading with regulation-up and non-spinning reserve) in RTPD. Note that the upward flexible ramping portion $FRU_{i,t}$ still needs to satisfy the 5-minute ramping capability limit.

The day-ahead spinning reserve and flexible ramping awards are settled in day-ahead market at the corresponding day-ahead marginal prices.

The amount of day-ahead procured upward flexible ramping that becomes spinning reserve in RTPD will be paid in day-ahead market at the day-ahead upward flexible ramping marginal price, and will be paid in RTPD at the difference between the spinning reserve marginal price and the flexible ramping marginal price, i.e. RTPD spinning reserve marginal price – RTPD upward flexible ramping marginal price, which has been proved to be non-negative.

The amount of day-ahead procured non-contingent spinning reserve that becomes upward flexible ramping headroom in RTPD has been paid in day-ahead market at the day-ahead spinning reserve marginal price, and will not be paid in RTPD, but wait till RTD for settlement. If the capacity is dispatched for energy in RTD, it will receive energy payment. If the capacity is held as flexible ramping capability in RTD, it will receive flexible ramping payment.

The converted portion will be subject to the spinning reserve "No Pay" and flexible ramping "No Pay" evaluation. The payment for the corresponding disqualified amount will be taken back based on the corresponding prices.

2.3 PROCURING FLEXIBLE RAMPING IN RTD

In RTPD, the flexible ramping headroom is created on a 15-minute interval basis. The RTPD headroom is the available flexible ramping capability before the imbalance difference gets realized. In RTD, imbalance differences are realized in three 5-minute intervals. In each of the three 5-minute intervals, RTD will fully release the flexible ramping headroom capacity, which includes the day-ahead flexible ramping procurements, for dispatch in response to realized imbalance difference, and re-procure flexible ramping capacity. The RTD re-procurement target is calculated as follows:

$$R_t^{FRU,RTD} = \min\{NL_{t+1}^{RTPD} + R_{t+1}^{FRU,RTPD} - NL_t^{RTPD} - RLZ_t^{RTD}, R_t^{FRU,5min}\}$$

$$R_t^{FRD,RTD} = \min\{-NL_{t+1}^{RTPD} - R_{t+1}^{FRD,RTPD} + NL_t^{RTPD} - RLZ_t^{RTD}, R_t^{FRD,5min}\}$$

For the upward flexible ramping procurement target, the first bound $NL_{t+1}^{RTPD} + R_{t+1}^{FRU,RTPD} - NL_t^{RTPD} - RLZ_t^{RTD}$ is the next RTD interval t+1 net load 95% confidence upper bound $NL_{t+1}^{RTPD} + R_{t+1}^{FRU,RTPD}$ (including both RTPD net load and the RTPD 95% confidence flexible ramping headroom) minus the current RTD interval t realized net load (including both RTPD net load and RTD realized imbalance difference). The first bound is the upper 95% confident level for the cumulative imbalance difference in the next RTD interval. The first bound is referred as the 15-minute bound. The second bound $R_t^{FRU,5min}$ is the 5 minutes incremental confidence interval, i.e. it is 95% sure that for the next RTD interval the net load can go up for at most $R_t^{FRU,5min}$ MW. The second bound is referred as the 5-minute bound. The RTD upward flexible ramping procurement target is set to the minimum of the two bounds.

The RTD upward flexible ramping requirement calculation is illustrated in Figure 4. The data used to plot Figure 4 is listed in Table 1. Note that it is possible that the requirement is negative. However, because the sum of flexible ramping flexible ramping awards is greater than equal to the requirement, a negative requirement will only make the constraint non-binding, and will not cause any inadvertent results.

Similarly, there are also two bounds that limit the downward flexible ramping procurement target, i.e. the 15-minute bound and the 5-minute bound as shown in the $R_t^{FRD,RTD}$ equation above. Table 1 also demonstrates how the downward requirement is calculated.

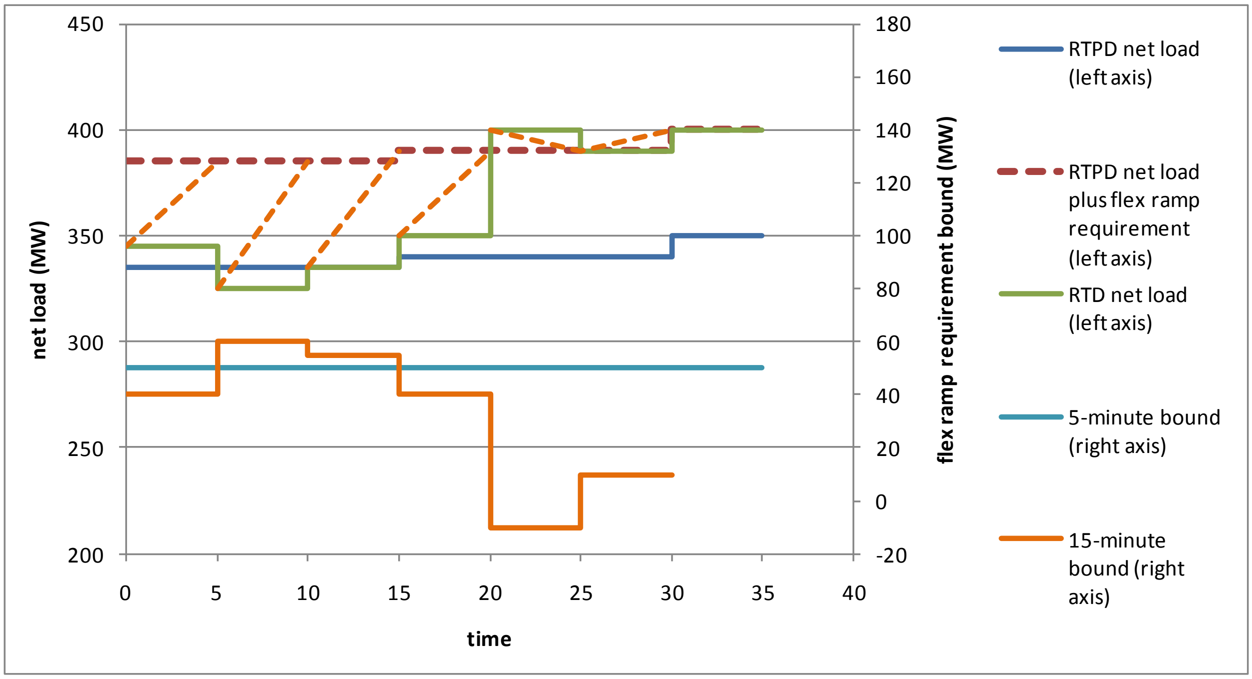

FIGURE 4: RTD UPWARD FLEXIBLE RAMPING REQUIREMENT

		RTPD1			RTPD2			RTPD3
		RTD1	RTD2	RTD3	RTD4	RTD5	RTD6	RTD7
	RTPD net load	335	335	335	340	340	340	350
	RTD realization	10	-10	0	10	60	50	50
	RTD net load	345	325	335	350	400	390	400
upward	RTPD requirement	50	50	50	50	50	50	50
	15 minute bound	40	60	55	40	-10	10	
	5 minute bound	50	50	50	50	50	50	50
	RTD requirement	40	50	50	40	-10	10	
downward	RTPD requirement	40	40	40	40	40	40	40
	15 minute bound	60	40	45	60	110	90	
	5 minute bound	40	40	40	40	40	40	40
	RTD requirement	40	40	40	40	40	40	

TABLE 1: CALCUALTE RTD FLEXIBLE RAMPING REQUREMENT

The real-time flexible ramping bids will be part of the RTD objective function. The day-ahead flexible ramping awards will be modeled as bidding zero for flexible ramping. The additional RTD flexible ramping award on top of the day-ahead unconverted flexible ramping award that contributes to meet the RTD procurement target will be paid the RTD flexible ramping marginal price. If a resource's RTD flexible ramping award is less than or equal to its day-ahead award (the amount remaining after RTPD conversion), it will not have RTD flexible ramping settlement. For example, a resource has day-ahead upward flexible ramping award of 100 MW, and 10 MW is converted into spinning reserve in RTPD, then its remaining day-ahead award is 90 MW. If the resource has 80 MW of flexible ramping award in RTD, which is less than 90, it will not be paid in RTD for flexible ramping. However, if the resource has 95 MW of flexible ramping in RTD, it will receive the RTD flexible ramping payment for 95 – 90 = 5 MW.

Procuring flexible ramping in RTD has several advantages over doing it in RTPD.

- Flexible ramping capacity can be procured from difference resources in RTD, and the resources that can provide flexible ramping in RTD are not limited to those that have headroom in RTPD.
- The flexible ramping capability evaluated in RTD is more reliable than that in RTPD because it is based on more accurate information in real-time.
- RTD flexible ramping price reflects true lost opportunity of providing energy. Only resources that lost the opportunity of providing energy in the current interval due to maintaining ramping capability to meet future variability and uncertainties will be paid for providing flexible ramping.

Some stakeholders expressed concerns about the flexible ramping opportunity cost in RTPD and the potential for such opportunity cost not being lost if resource were dispatched for energy in RTD. By procuring the flexible ramping capability in RTD, and after the imbalance realization in the binding interval, the ISO's new proposal provides a transparent way to price the flexible ramping products considering true opportunity cost. The opportunity cost is appropriately accounted for because the a resource that provides flexible ramping in RTD indeed loses the opportunity of being dispatched for energy for the same RTD interval.

2.4 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

Stakeholders have requested additional detail regarding how the ISO will settle and ensure compliance with awarded flexible ramping product service. In response the ISO proposes the following additional detail of settlement of flexible ramping products in previous sections. This section will summarize them, and also briefly discuss the no-pay rules.

The settlement of flexible ramping products can have the following elements.

- Day-ahead procured flexible ramping products will be settled at the day-ahead flexible ramping prices.

- Day-ahead upward flexible ramping award that is converted to spinning reserve in RTPD will receive the difference between the RTPD spinning reserve price and the RTPD upward flexible ramping price for the converted amount.

- RTD procured additional flexible ramping products on top of the unconverted day-ahead awards will be settled at RTD energy price. If the RTD flexible ramping award is less than the day-ahead award (the amount remaining after RTPD conversion), the resource will not receive RTD flexible ramping award.

Payment for flexible ramping products will be included in bid cost recovery to offset the revenue. If the ISO commits a resource to procure flexible ramping products, this is considered as ISO commitment and the resource is allowed to recover the start up cost, minimum lost, energy cost, and flexible ramping cost. If a resource self commits, then the resource is only allowed to recover the energy cost and flexible ramping cost above the self schedule level.

"No pay" will be performed in a similar way as spinning reserve except that the evaluation of availability will be based on the meter and the ramp-able window. Currently "no pay" for spinning reserve is evaluated based on capacity rather than the dispatchable window. The payment for the corresponding disqualified flexible ramping amount will be taken back based on the corresponding price. If the conversion between the flexible ramping and spinning reserve happens in RTPD, the converted portion will also be subject to the spinning reserve "No Pay" and flexible ramping "No Pay" evaluation.

3. EXAMPLE

In this section, a numerical example will be discussed to illustrate how the flexible ramping products interact with energy and ancillary services, how they are priced, and how they are settled. The example will go through day-ahead market and real-time markets continuously. Readers should pay close attention to the data change in each market, such as load, flexible ramping requirements, unit outage, and so on.

3.1 DAY-AHEAD MARKET

There are seven units in the system: G1, G2, G3, G4, G5, G6 and G7. The day-ahead awards are listed in Table 2, in which only non-zero values are shown. The day-ahead market prices are listed in Table 3. Note that the marginal price for regulation-up is not equal to the corresponding shadow price due to ancillary service substitution. The regulation-up marginal price ($2) is equal to the sum of the regulation-up shadow price ($1), the spinning reserve shadow price ($1) and the non-spin reserve shadow price ($0).

To make the example concise, only the day-ahead awards and prices are provided, but the bids and optimization details are omitted. We will demonstrate the market co-optimization with energy and ancillary services through the RTPD market.

gen	Energy	Reg-up	Reg-down	Spinning reserve	Non-spin reserve	Flex-ramp up	Flex-ramp down
G1	20						
G2	190						
G3	10						
G4	10						
G5	35					30	30
G6	1			9 non-contingent			
G7	15	10	10	11 non-contingent			

TABLE 2: DAY-AHEAD MARKET AWARDS

Product	Shadow Price ($/MWh)	Marginal Price ($/MWh)
Energy	40	40
Regulation-up	1	2
Regulation-down	1	1
Spinning reserve	1	1
Non-spinning reserve	0	0
Upward flexible ramping product	2	2
Downward flexible ramping product	2	2

TABLE 3: DAY-AHEAD MARKET PRICES

3.2 RTPD MARKET

Now consider the RTPD market with the day-ahead awards listed in Table 2. For simplicity, consider only one interval in RTPD with $T = 1$, and neglect the transmission network impacts and power losses.

The requirements are

- load is 340 MW,
- regulation up requirement is 10 MW,
- regulation down requirement is 10 MW,
- spinning reserve requirement is 20 MW,

- non-spinning reserve requirement is 0 MW,
- upward flexible ramping product requirement is 50 MW,
- downward flexible ramping product requirement is 40 MW.

Assume G7 is offline in RTPD due to forced outage, so it cannot provide regulation services and spinning reserve. G7's day-ahead ancillary services need to be replaced by other resources.

The RTPD ramp sharing coefficients are

- $\alpha = 0.75$, which means ramp sharing between regulation and energy is not allowed,
- $\beta = 0$, which means ramp sharing between spinning reserve and energy is allowed,
- $\gamma = 1.0$, which means ramp sharing between flexible ramping product and energy is not allowed,
- $\eta = 0$, which means ramp sharing between non-spinning reserve and energy is allowed.

The bids and generator parameters are listed in Table 4 and Table 5. Note that in Table 4, "no bid" for flexible ramping products means that the bid will be assumed to be zero, while "no bid" for ancillary services means the resources are not qualified to provide such ancillary services.

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gen	EN Bid	RU bid	RD bid	SP bid	NS bid	FRU bid	FRD bid	En init	RU init	RD init	SP init	NS init	FRU init	FRD init
G1	25	10	10	10	10	1.4	3	20	0	0	0	0	0	10
G2	30	1.1	1.2	0	0	4	2	180	10	10	0	0	10	0
G3	35	3	3	0	0	3	1	89	10	0	0	0	0	0
G4	50	2	2	0	0	2.3	3	10	0	0	0	0	5	0
G5	53	No	No	No	No	SS	SS	30	0	0	0	0	30	30
G6	60	No	No	SS	No	No	No	1	0	0	9	0	0	0

EN – energy   RU – regulation up   RD – regulation down   SP – spinning reserve
NS – non-spinning reserve   FRU – flexible ramping up   FRD – flexible ramping down
No – no bid   SS – self schedule/provision

TABLE 4: RTPD BIDS AND GENEARTOR INITIAL OPERATING CONDITIONS

gen	Pmin	Pmax	operational ramp rate	regulation ramp rate
G1	10	45	5	5
G2	10	200	3	3

G3	10	300	1	1
G4	10	21	8	8
G5	5	65	6	6
G6	1	10	1	1

TABLE 5: GENERATOR OPERATING LIMITS AND RAMP RATES

Given the system requirements, the optimal RTPD schedules of energy, ancillary services and flexible ramping products are listed in Table 6, and the corresponding marginal prices are listed in Table 7.

gen	Energy	Reg-up	Reg-down	Spinning reserve	Non-spin reserve	Flex-ramp up	Flex-ramp down
G1	45						10
G2	175	10	10	5		5	
G3	74			10			
G4	10			1		10	
G5	35					30	30
G6	1			4		5	

TABLE 6: RTPD OPTIMAL SCHEDULES

Product	Shadow Price ($/MWh)	Marginal Price ($/MWh)
Energy	30	30
Regulation-up	1.1	1.1
Regulation-down	1.2	1.2
Spinning reserve	0	0
Non-spinning reserve	0	0
Upward flexible ramping product	2.3	2.3
Downward flexible ramping product	1.4	1.4

TABLE 7: RTPD PRICES

Because G7 is offline due to forced outage, it cannot provide regulation services and spinning reserve. G2 replaces G7 to provide regulation services in RTPD. G7's spinning reserve is also replaced by other resources.

G6 has 9 MW non-contingent spinning reserve award in day-ahead. As discussed in section 2.2**Error! Reference source not found.**, this 9 MW of non-contingent spinning reserve may be converted to upward flexible ramping product if upward flexible ramping is more valuable than spinning reserve. As shown in Table 7, upward flexible ramping marginal price is $2.3/MWh, while spinning reserve marginal price is $0/MWh. Therefore, it is economic to convert G6's non-contingent reserve into upward flexible ramping product. As expected, 5 MW from G6's day-ahead award is converted into upward flexible ramping, and 4 MW remains as spinning reserve. This is because G4 has 1 MW/minute ramp rate, and thus can only provide 5 MW flexible ramping. The 5 MW of award converted into upward flexible ramping will not be settled in RTPD, but will be re-evaluated in RTD.

The flexible ramping headroom is created in RTPD, but it is not financially binding. In other words, the resources that are meeting the RTPD flexible ramping requirements will not be paid in RTPD.

3.3 PROCURING FLEXIBLE RAMPING PRODUCTS IN RTD

In RTD, the imbalance difference is fully realized for the binding interval. The flexible ramping capability kept in previous RTD interval will be fully released in the current RTD interval to meet the realized imbalance difference. Also, the current RTD interval needs to procure flexible ramping capability to meet the imbalance difference to be realized in the next RTD interval.

Again, assume RTD performs a single interval optimization. Let's consider binding interval RTD4. The data for calculating the RTD flexible ramping requirement has been listed in Table 1, and we relist the table here for convenience. In RTD4, the realized imbalance difference is 10 MW, and the upward and downward flexible ramping requirements are both 40 MW.

The RTD dispatch and flexible ramping award are listed in Table 8, in which the zero values are omitted. The lower and upper operating limits are the resources' adjusted Pmin and Pmax due to providing ancillary services. The RTD prices are listed in Table 9.

		RTPD1			RTPD2			RTPD3
		RTD1	RTD2	RTD3	RTD4	RTD5	RTD6	RTD7
	RTPD net load	335	335	335	340	340	340	350
	RTD realization	10	-10	0	10	60	50	50
	RTD net load	345	325	335	350	400	390	400
upward	RTPD requirement	50	50	50	50	50	50	50
	15 minute bound	40	60	55	40	-10	10	…
	5 minute bound	50	50	50	50	50	50	50
	RTD requirement	40	50	50	40	-10	10	…
downward	RTPD requirement	40	40	40	40	40	40	40
	15 minute bound	60	40	45	60	110	90	…
	5 minute bound	40	40	40	40	40	40	40
	RTD requirement	40	40	40	40	40	40	…

This table is the same as Table 1.

gen	Energy	Lower operating limit	Upper operating limit	Flex-ramp up	Flex-ramp down
G1	45	10	45		25
G2	185	20	185		
G3	94	10	290		5
G4	15	10	20	5	5
G5	10	5	65	30	5
G6	1	1	6	5	

TABLE 8: RTD DISPATCH AND FLEXIBLE RAMPING AWARD

Product	Marginal Price ($/MWh)
Energy	49
Upward flexible ramping product	3.3

Downward flexible ramping product	4

TABLE 9: RTD PRICES

3.4 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

In this section, we summarize the settlement for flexible ramping awards in day-ahead market and RTD. The day-ahead award will be paid the day-ahead flexible ramping price. The RTD incremental award from day-ahead award will be paid the RTD flexible ramping price. G1, G2 and G4 do not have day-ahead flexible ramping award, so they only receive RTD payments. G5 has day-ahead upward and downward flexible ramping award 30 MW, and its RTD flexible ramping award is less than 30 MW, so it only receives day-ahead payment but receives no RTD payment.

	Day-ahead market settlement (award times price)		RTD incremental award (5/60 times award times price)	
gen	flex-ramp up (price = $2)	flex-ramp down (price = $2)	Flex-ramp up (price = $3.3)	Flex-ramp down (price = $4)
G1				5/60*25*4
G2				
G3				5/60*5*4
G4			5/60*5*3.3	5/60*5*4
G5	30*2	30*2	5/60*0*3.3	5/60*0*4
G6			5/60*5*3.3	
G7				

TABLE 10: FLEXIBLE RAMPING AWARD SETTLEMENT

4. OTHER DESIGN ELEMENTS

4.1 GRID MANAGEMENT CHARGES

The flexible ramping product will be subject to the bid segment fee and the market services fee based upon awarded MW of flexible ramping products. The treatment is the same as will be implemented for other ancillary services in January 2012.

4.2 FLEXIBLE RAMPING PRODUCT DATA RELEASE

The ISO will publish procurement targets, prices, and other data similar to what is currently provided for other ancillary services products.

5. COST ALLOCATION

5.1 CHANGES FROM STRAW PROPOSAL

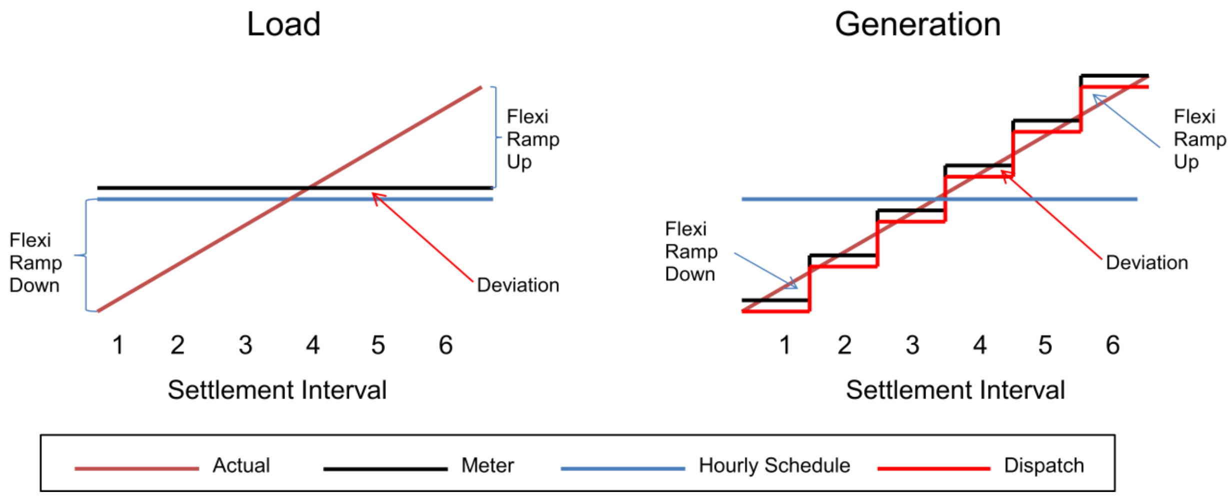
Some stakeholders suggest and the ISO agrees that allocation of reserves and application of cost-causation methodologies require broader review rather than a targeted application with the introduction of the flexible ramp product. As a result the ISO now proposes to clarify and modify the allocation of flexible ramping product. The ISO proposes to allocate cost of the flexible ramping product the same way regulation obligations are allocated or metered demand. The ISO also proposes to maintain transparency regarding the monthly contributors to flexible ramping product. The ISO also proposes to maintain the ability for parties to trade the flexible ramping financial obligations. However, the ISO proposes modify its straw proposal by eliminating allocations of costs attributable to generation resources, imports and export at the end of the month by crediting back costs received from generation resources, imports and exports to load.

The ISO intends to commence a separate stakeholder process in Q1 2012 to review cost allocation across all ISO products.

5.3 METER AND SCHEDULE GRANULARITY

Since deviations of both load and generation are considered in the procurement target for flexible ramping products, a consistent metering interval would be necessary to implement a single measurement of deviations for both load and generation. However, load is metered hourly and internal generation is metered on a ten minute basis. As illustrated in Figure 6 below, while load and generation have similar deviations based upon their meter, actual load would drive a larger portion of the flexible ramping product procurement requirements. Thus existing meter data for load would under represent the procurement requirements attributable to load deviations and over represent the procurement requirements attributable to generation deviations.

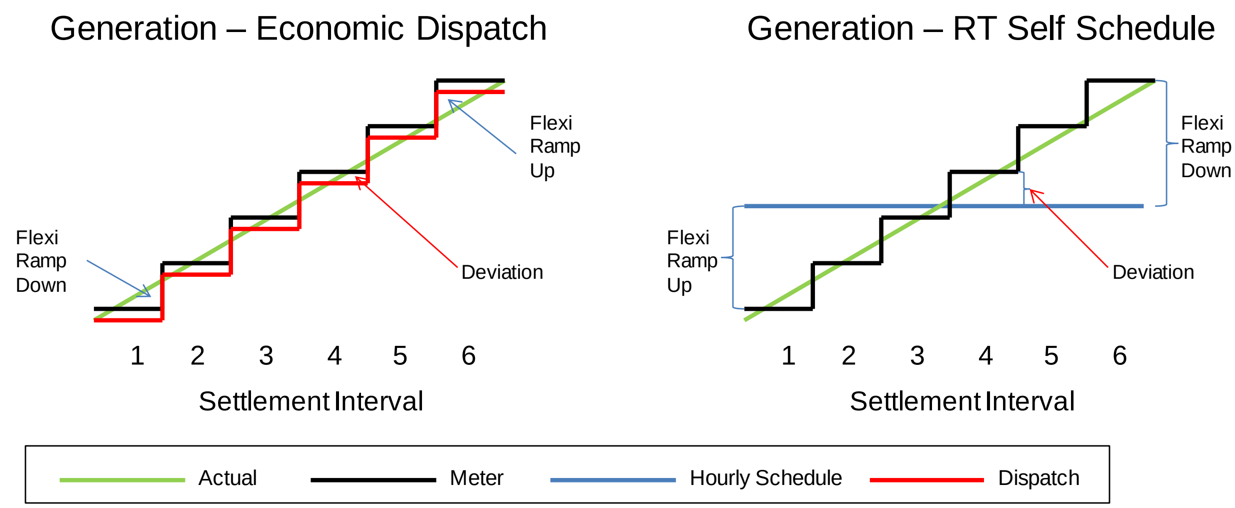
FIGURE 5 - COMPARISON OF LOAD AND GENERATION DEVIATIONS



The meter granularity of load also results in netting of positive and negative deviations on an hourly basis. In the example above, both load and generation are driving requirements for both flexible ramping up and flexible ramping down. But since the hourly meter value of load is divided evenly into the six settlement intervals, the load deviations calculated for settlement purposes would be netted in to a single direction (in this case deviating above the hourly schedule). The procurement requirements for flexible ramping are determined based upon the gross deviations that may occur due to variability and uncertainties between RTPD and RTD, not the net deviations for an hour. While the five minute meter data could more accurately measure deviations to assess the impact on procurement of the flexible ramping product, the existing 10 minute meter data from generation sufficiently minimizes the impact of netting across two 5 minute dispatches. In a given hour, a resource can drive the procurement of both flexible ramping up and flexible ramping down based upon negative and positive deviations.

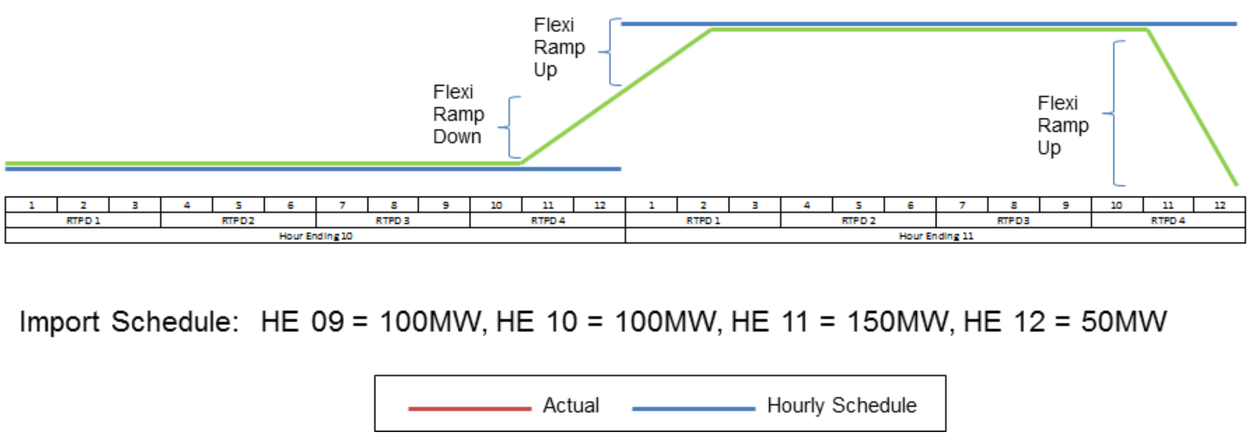
However, when determining the deviations for generation resources, imports and exports it is necessary to further segment the measurement of deviations. The reference point to measure deviations by supply is not aligned for all resources. For resources that respond to five minute dispatch the deviation should be measured from their instructed energy and not the hourly schedule. The reference point to measure deviations for generation with self schedules in real time would be the hourly schedule. In addition, reference point of imports and exports would be the hourly schedule. Flexible ramping products are not procured for generation which has deviated from its hourly schedule in response to ISO dispatch. As Figure 7 below shows, self scheduled generation which deviates is driving a larger flexible ramping procurement target than a generation resource which has responded, although not perfectly, to ISO dispatch.

FIGURE 6 - COMPARISON OF GENERATION WITH ECONOMIC DISPATCH AND SELF SCHEDULES



An additional segmentation has been added in the revised straw proposal for static intertie hourly schedules. Static hourly schedules for Imports and Exports allow a twenty minute ramp for hourly schedule changes. As shown in Figure 8, when a static hourly import schedule increases, the ISO must have sufficient downward ramping capability for the final two RTD intervals from internal generation to respond to downward dispatches for up to fifty percent of the hourly schedule increase. Then in the subsequent hour, the ISO must have sufficient upward ramping capability for the first two RTD intervals from internal generation able to respond to upward dispatches for up to fifty percent of the hourly schedule increase. The variability and uncertainties surrounding hourly intertie ramps is an additional input in determining the quantity of flexible ramping products.

FIGURE 7 - FLEXIBLE RAMPING REQUIREMENT FROM INTERTIE RAMPS

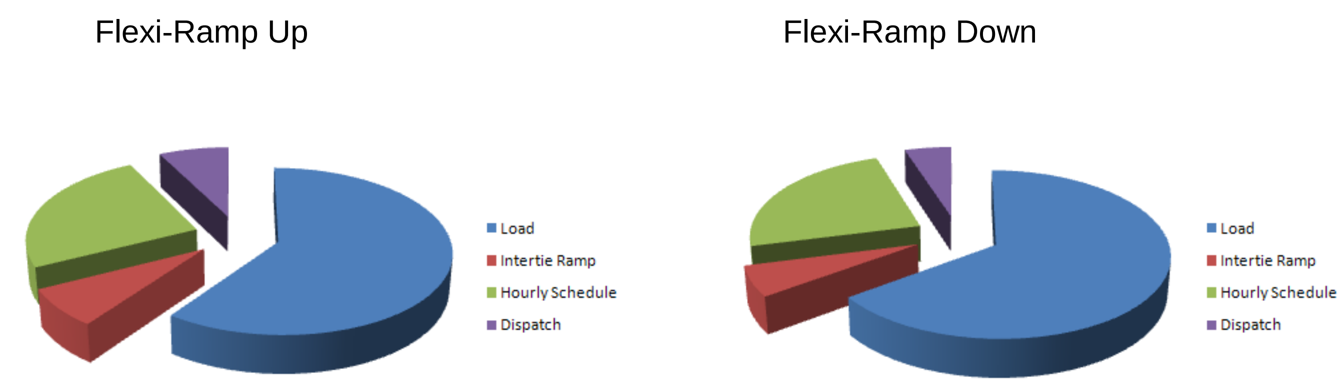


If an intertie schedule does not e-tag its hourly schedule from the HASP, any difference gives rise to deviations that are captured as operational adjustments. The changes in hourly static schedules are similar to deviations from internal generation hourly schedules which can drive a portion the total flexible ramping product costs.

5.4 SETTLEMENT CHARGES TO MEASURE DEVIATIONS

The ISO proposes to create separate cost buckets for flexible ramping up and flexible ramping down. The costs for procuring flexible ramping products in the day-ahead market and real-time market will be combined into a single cost bucket for each direction. This information will be provided to market participants in order to improve transparency of flexible ramping procurement requirements.

FIGURE 8 - COST ALLOCATION PIES AND SLICES



Because of the different reference points to measure deviations, the ISO proposes to further segment the costs in to four slices: (1) costs attributable to load, (2) cost attributable to intertie ramps, (3) costs attributable to deviations from hourly schedules, and (4) costs attributable to deviations from ISO dispatch. Flexible ramping up costs will be driven by negative deviations. Flexible ramping down costs will be driven by positive deviations. Positive and negative deviations will not be netted across settlement intervals in the data released regarding deviations for each slice. However, within the settlement interval the deviations will net, that is a positive deviation in the first five minute dispatch would offset a negative deviation in the second five minute interval given that the meter interval is ten minutes. The deviations will be calculated by scheduling coordinator for slice 1, slice 2, and operational adjustments for imports/exports. The deviations will be calculated for internal generation and dynamic transfers at a resource level for slices 3 and 4, not aggregated by scheduling coordinator, because the objective is a resource specific assessment of the impact to the flexible ramping procurement target.

The ISO proposes to use existing settlement calculations measure deviations for each of the slices. Table 12 summarizes flexible ramping buckets proposed and the deviation metric to use for providing transparency and tracking sources of imbalance differences between RTPD and RTD.

TABLE 11 - SETTLEMENT CALCULATION FOR COST REPORTING

Pie Slice	Deviation Metric
UP – Load	Regulation Up Ancillary Service (AS) Obligation
UP - Intertie Ramp	Absolute Value Net Hourly Schedule Change of Import & Export,

	Wheels Exempt
UP – Hourly Schedule	Negative Uninstructed Imbalance Energy 2 Negative Operational Adjustments
UP – Dispatch	Negative Uninstructed Imbalance Energy 1
DOWN – Load	Regulation Down AS Obligation
DOWN – Intertie Ramp	Absolute Value Net Hourly Schedule Change of Import & Export, Wheels Exempt
DOWN – Hourly Schedule	Positive Uninstructed Imbalance Energy 2 Positive Operational Adjustments
DOWN – Dispatch	Positive Uninstructed Imbalance Energy 1

Based upon stakeholder input, the ISO further clarified that load will be allocated based upon regulation AS obligations. This addresses concerns regarding the treatment of load under Metered Subsystems (MSS). The Regulation Up to Load Obligation ratio for the hour is calculated by dividing the Total Regulation Up Requirement for the hour by the ISO Hourly Total metered Demand. The Regulation Down to Load Obligation ratio for the hour is calculated by dividing the Total Regulation Down Requirement for the hour by ISO Hourly Total metered Demand. Exports are not considered metered demand.

5.6 SETTLEMENT AND REPORTING OF FLEXIBLE RAMPING COSTS

Since flexible ramping is procured based upon forecasted variability and uncertainties, when a resource deviates in a specific settlement interval, it cannot be concluded that the resource's actual deviation caused the flexible ramping product to be procured for that settlement interval. As a result, the ISO proposes to calculate the procurement impact from generation resources, imports and exports based upon the total cost and total deviations for the month.

Inter-SC trades currently support the daily transaction of energy, residual unit commitment (RUC) obligation, and AS obligation, between scheduling coordinators. The ISO proposes to expand the inter-SC trade functionality to allow the monthly transaction of the flexible ramping product obligation. This will allow supply resources and load with the opportunity to trade flexible ramping cost obligations in order to allow an individual supply resource to manage their deviations and impact on flexible ramping procurement targets.

5.7 FLEXIBLE RAMPING COST & DEVIATION DATA RELEASE

The ISO proposes to publish on a daily basis the month to date flexible ramp cost procured, the MWh deviations subject to cost allocation, and the per MWh rate of deviations. The data will be provided for both flexible ramping up and flexible ramping down and for each of the for cost buckets.

6. PLAN FOR STAKEHOLDER ENGAGEMENT

Item	Date
Post Revised Straw Proposal	11/28/11
Stakeholder Meeting	12/5/11
Stakeholder Comment	12/12/11
Post Draft Final Proposal	01/05/12
Stakeholder Meeting	01/12/12
Stakeholder Comment	01/19/12
Board of Governors	02/16/11

7. NEXT STEPS

The ISO will discuss the revised straw proposal with stakeholders at a meeting to be held on December 5, 2011. The ISO is seeking written comments on the revised straw proposal by December 12, 2011. Stakeholder comments should be sent to FRP@caiso.com.

APPENDIX A: NOMENCLATURE

$FRU_{i,t}$ upward flexible ramping from resource *i* at time interval t

$FRD_{i,t}$ downward flexible ramping from resource *i* at time interval t

$RU_{i,t}$ regulation-up from resource *i* at time interval t

$RD_{i,t}$ regulation-down from resource *i* at time interval t

$SP_{i,t}$ spinning reserve from resource *i* at time interval t

$NS_{i,t}$ non-spinning reserve from resource *i* at time interval t

$P_{i,t}$ active power from resource *i* at time interval t

P_i^{Min} active power lower limit of resource *i*

P_i^{Max} active power upper limit of resource *i*

RR_i^{OP} operational ramp rate of resource *i*

RR_i^{REG} regulation ramp rate of resource *i*

R_u^{FRU} upward flexible ramping requirement from variability or uncertainty source u

R_u^{FRD} downward flexible ramping requirement from variability or uncertainty source u

$R_t^{FRU,RTPD}$ total upward flexible ramping requirement in RTPD interval t

$R_t^{FRD,RTPD}$ total downward flexible ramping requirement in RTPD interval t

$R_t^{FRU,5min}$ upward 5-minute ramp-able bound in RTD interval t

$R_t^{FRD,5min}$ downward 5-minute ramp-able bound in RTD interval t

NL_t^{RTPD} net load in RTPD interval t

RLZ_t^{RTD} realized total imbalance difference in RTD interval t

UU the set of upward variability or uncertainty sources

UD the set of downward variability or uncertainty sources

I_{FR} the set of resources that bid into the market to provide flexible ramping

I_{FRU}^{DA} the set of upward flexible ramping awards in day-ahead market

I_{SPIN}^{DA} the set of non-contingent spinning awards in day-ahead market and non-contingent non-spinning awards in day-ahead market that become online in RTPD

$FRU_{i,t}^{DA}$ upward flexible ramping procured in day-ahead from resource *i* at time interval t

$SPIN_{i,t}^{DA}$ non-contingent spinning reserve procured in day-ahead market or non-contingent non-spinning reserve procured in day-ahead market that is online in RTPD from resource i at time interval $t\lambda_t^{FRU}$ shadow price of upward flexible ramping constraint at time interval t

λ_t^{FRD} shadow price of downward flexible ramping constraint at time interval t

$C_{i,t}^{FRU}(FRU_i)$ bid cost of upward flexible ramping from resource i at time interval t

$C_{i,t}^{FRD}(FRD_i)$ bid cost of downward flexible ramping from resource i at time interval t

MT market clearing interval length: $MT = 60$ for day-ahead market, $MT = 15$ for RTPD, $MT = 5$ for RTD

T total intervals in the look-ahead optimization: $T = 24$ for day-ahead market, $T \in [4,18]$ for RTPD

α regulation ramp sharing coefficient

β spinning reserve ramp sharing coefficient

γ flexible ramping product ramp sharing coefficient

η non-spinning reserve ramp sharing coefficient

SLK_t^{FRU} relaxed amount of upward flexible ramping product requirement

SLK_t^{FRD} relaxed amount of downward flexible ramping product requirement

APPENDIX B: CO-OPTIMIZING FLEXIBLE RAMPING PRODUCTS WITH ENERGY AND ANCILLARY SERVICES

The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[7] We will discuss the changes to the objective function and constraints on top of Wu and Rothleder's model due to the addition of the flexible ramping products. The meanings of the variables used in this section are explained in Appendix A.

For simplicity in this discussion, assume the operational ramp rate is a constant for each resource. The ISO is able model dynamic ramp rates,[8] which is a function of the generation output level, and the following model can be generalized to dynamic ramp rates without problem. As a convention, assume ramp rates are specified in MW/minute.

The change to the objective function is to add the bid costs from the flexible ramping products:

$$\sum_{t=1}^{T}\sum_{i\in I_{FR}} C_{i,t}^{FRU}(FRU_{i,t}) + \sum_{i\in I_{FR}} C_{i,t}^{FRD}(FRD_{i,t})$$

The changes to the constraints involving flexible ramping are as follows.

Five-minute upward flexible ramping capability limit This constraint ensures that a resource's upward flexible ramping product award does not exceed what it can ramp in 5 minutes.

$$\frac{FRU_{i,t}}{RR_i^{OP}} \leq 5$$

Five-minute downward flexible ramping capability limit This constraint ensure that a resource's downward flexible ramping product award does not exceed what it can ramp in 5 minutes.

$$\frac{FRD_{i,t}}{RR_i^{OP}} \leq 5$$

Ten-minute upward ancillary service and flexible ramping limit This constraint ensures the total amount of upward reserves (regulation-up, spinning, and non-spinning) awards and the upward flexible ramp product award does not exceed what the resource can ramp in 10 minutes.

$$\frac{RU_{i,t}}{RR_i^{REG}} + \frac{FRU_{i,t} + SP_{i,t} + NS_{i,t}}{RR_i^{OP}} \leq 10$$

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[7] Tong Wu, Mark Rothleder, Ziad Alaywan, and Alex D. Papalexopoulos, "Pricing Energy and Ancillary Services in Integrated Market Systems by an Optimal Power Flow," *IEEE Transactions on Power Systems*, pp.339-347, 2004.

[8] See CAISO Technical Bulletin "Dynamic Ramp Rate in Ancillary Service Procurement" for details, http://www.caiso.com/Documents/TechnicalBulletin-DynamicRampRate_AncillaryServiceProcurement.pdf

Ten-minute downward ancillary service and flexible ramping limit This constraint ensures the total amount of regulation-down award and downward flexible ramping product award does not exceed what the resource can ramp in 10 minutes.

$$\frac{RD_{i,t}}{RR_i^{REG}} + \frac{FRD_{i,t}}{RR_i^{OP}} \leq 10$$

Upward ramping sharing[9] This constraint limits the extent to which the awards of regulation-up, spinning reserve, non-spinning reserve and upward flexible ramping product can share the resource's ramping capability with the ramp used to support the changes in energy.

$$P_{i,t} - P_{i,t-1} + \alpha \cdot \left(RU_{i,t} + RU_{i,t-1}\right) + \beta \cdot \left(SP_{i,t} + SP_{i,t-1}\right) + \gamma \cdot \left(FRU_{i,t} + FRU_{i,t-1}\right) + \eta \cdot \left(NS_{i,t} + NS_{i,t-1}\right) - MT \cdot RR_i^{OP} \leq 0$$

Downward ramping sharing[1] This constraint limits the extent to which the awards of regulation-down and downward flexible ramping product can share the resource's ramping capability with the ramp used to support the changes in energy.

$$-P_{i,t} + P_{i,t-1} + \alpha \cdot \left(RD_{i,t} + RD_{i,t-1}\right) + \gamma \cdot \left(FRD_{i,t} + FRD_{i,t-1}\right) - MT \cdot RR_i^{OP} \leq 0$$

Active power maximum limit This constraint limits the amount of the awards of energy schedule, upward reserves and upward flexible ramping product to be less than or equal to the resource's maximum operating capability.

$$P_{i,t} + RU_{i,t} + FRU_{i,t} + SP_{i,t} + NS_{i,t} \leq P_i^{Max}$$

Active power minimum limit This constraint limits the amount of energy schedule minus the awards of regulation-down and downward flexible ramping product to be greater than or equal to the resource's minimum operating level.

$$P_{i,t} - RD_{i,t} - FRD_{i,t} \geq P_i^{Min}$$

Upward flexible ramping requirement This constraint ensures that the total amount of upward flexible ramping product awards at least meets the requirement.

$$\sum_{i \in I_{FR}} FRU_{i,t} \geq \sum_{u \in UU} R_{u,t}^{FRU}$$

Downward flexible ramping requirement This constraint ensures that the total amount of downward flexible ramping product awards at least meets the requirement.

$$\sum_{i \in I_{FR}} FRD_{i,t} \geq \sum_{u \in UD} R_{u,t}^{FRD}$$

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[9] See CAISO Technical Bulletin "Simplified Ramping" for details of the ramp sharing constraints and coefficients, http://www.caiso.com/2437/2437db41245c0.pdf, August 2009.