Flexible Ramping Products

Draft Final Proposal

Lin Xu, Ph.D.

Market Analysis and Development

and

Donald Tretheway

Market and Infrastructure Policy

April 9, 2012

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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 resulting from the real-time unit commitment process (RTUC), also known as the real-time pre-dispatch (RTPD) process, and the position of units in real-time dispatch (RTD) sometimes lack sufficient ramping capability and flexibility to handle the 5-minute to 5-minute energy imbalances. 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 dispatchable flexibility in terms of ramping capability. The flexible ramping products specifically target the 5-minute RTD imbalances due to variability and uncertainties. The term "variability and uncertainties" is used in the ISO's 20% renewable portfolio standard study in the context of load following requirements.[2] Specifically, the variability may come from market granularity differences in load profile and variable energy resource supply. 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. Scheduling coordinators (SCs) will be allowed to offer ramping capabilities into the market, and the ISO will optimize such offers to economically meet the anticipated 5-minute imbalances. 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

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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

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 RTUC 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 and 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 RTUC 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 be insufficient 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 RTD the imbalances.

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 RTUC and RTD results in 5-minute variability to be realized in RTD. In addition, certain uncertainties are also realized after RTUC and before RTD. These post RTUC uncertainties include load forecast changes, variable energy resources production changes, uninstructed deviations, and forced outages. The post RTUC variability and uncertainties are continuously realized in 5-minute steps. Each RTD will "recourse"[3] to the realization in the first 5-minute interval. Approaching actual delivery time after

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

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 can only be handled by automatic generation controls (AGC), which are procured in day-ahead or corresponding RTUC as regulation services. The difference between the two categories of variability and uncertainties and how to address them are illustrated in Figure 2.

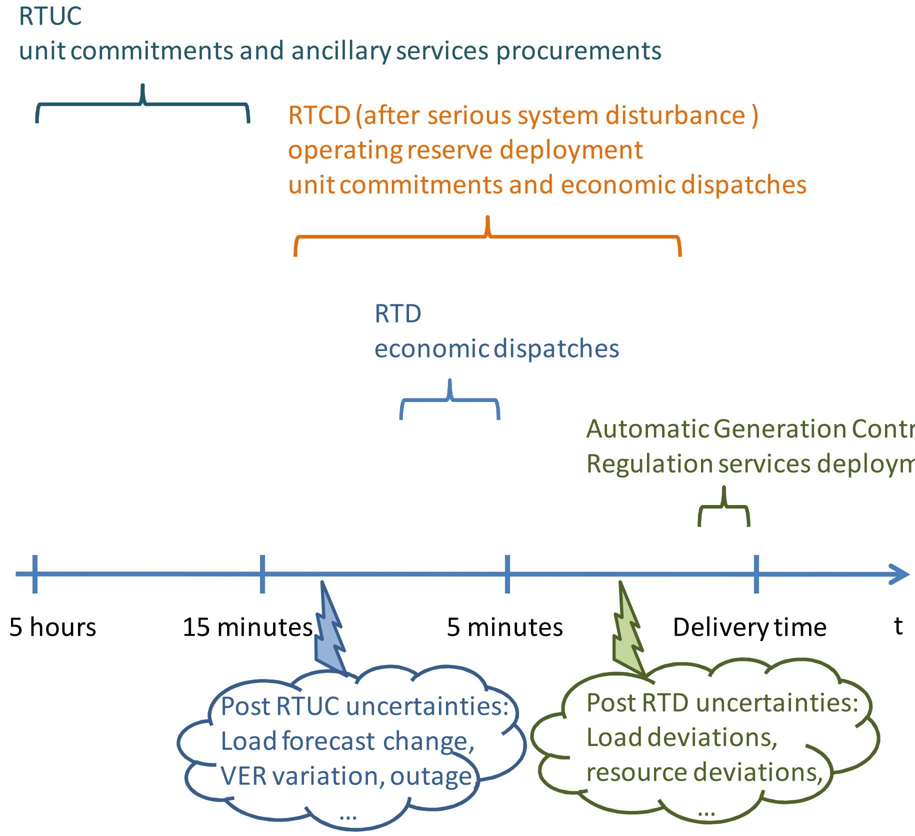

FIGURE 1: REAL-TIME MARKETS TIME FRAME

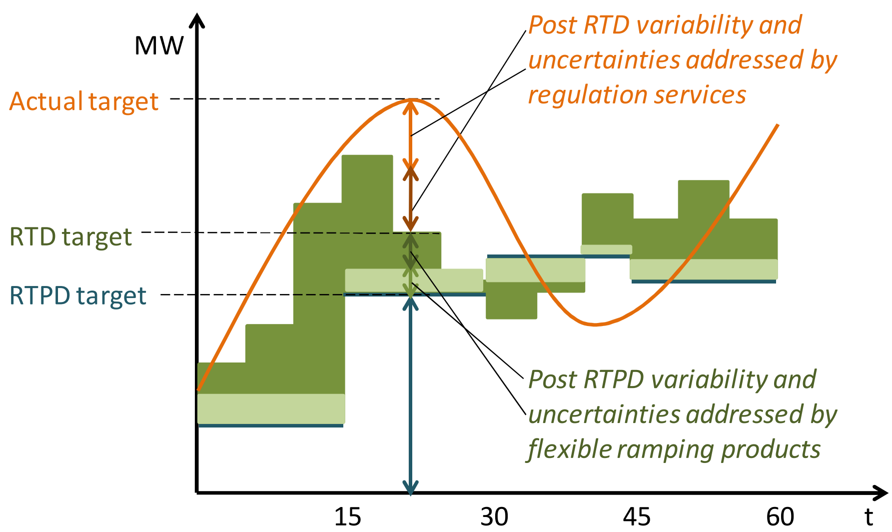

FIGURE 2: HANDLING VARIABILITY AND UNCERTAINTIES WITH FLEXIBLE RAMPING PRODUCTS AND REGULATION SERVICES

The objective of the flexible ramp product is to build dispatch flexibility in terms of ramping capability in RTD to meet imbalances that may arise in the future. Imbalances 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 RTUC, it is appropriate to consider the flexible ramp product quantifying the difference between net load in RTUC 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 RTUC commitment. The following conceptual relationships attempt to illustrate the relationship of load following and flexible ramp product and their associated contributions.

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

where

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

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

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

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

and

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

where

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

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

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

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

Figure 3 and Figure 4 attempt to graphically illustrate how flexible ramp and load following are determined using the forecast net load.

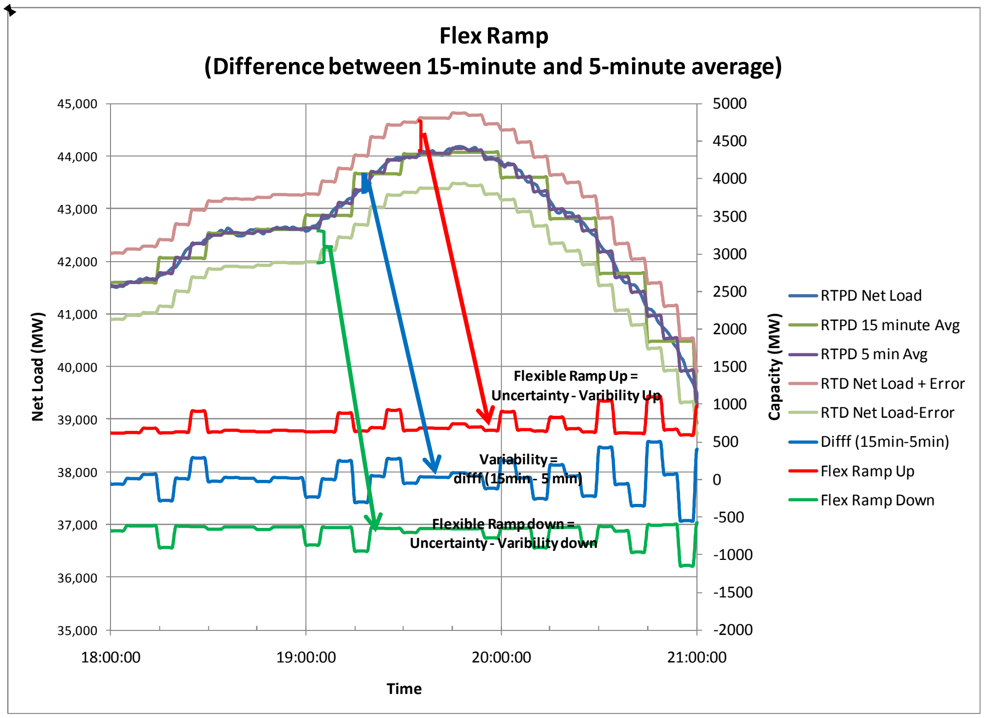

FIGURE 3: FLEXIBLE RAMP PRODUCT ILLUSTRATION

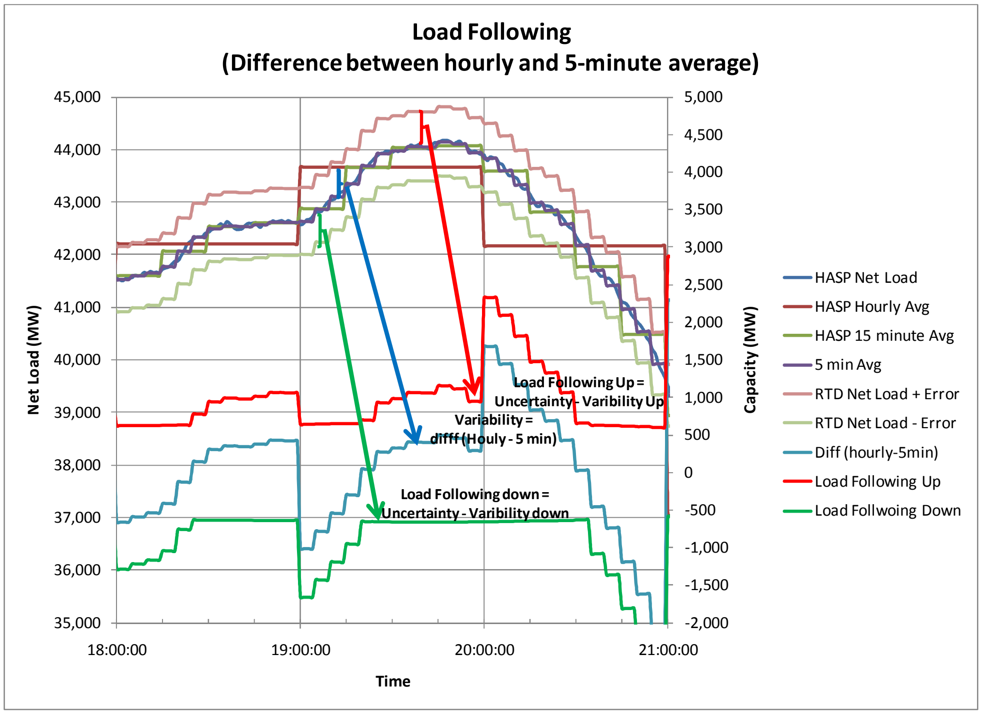

FIGURE 4: LOAD FOLLOWING ILLUSTRATION

Flexible ramping products have two major goals. One is to improve the ISO's dispatch flexibility, and the other is to do so in a cost effective way.

Flexible ramping products are 5-minute flexible capacities dispatchable by the ISO, which are able to deal with the energy imbalances in RTD. The flexible ramping consists of separate products in the upward and downward directions as the imbalances may be positive and negative. The imbalances 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 imbalances 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 to deal with RTD imbalances.

Due to the stochastic nature of power balance, the requirement for flexible ramping product does not have a fixed formula. The more we procure, the higher the probability that power balance can be maintained is, but it will incur more cost. An important aspect of flexible ramping product is cost effectiveness. The possible inadvertent results from losing power balance need to be evaluated against the procurement cost. Generally speaking, it is not cost effective to procure flexible ramping to maintain power balance with 100% confidence. The ISO intends to first procure the flexible ramping products partially (e.g. with 60% confidence level) in the integrated forward market (IFM), and then procure additional flexible ramping products in RTD to achieve higher confidence level (e.g. 95% confidence). The IFM can commit and acquire flexible ramping capability from long start units if necessary, so it is an important step to preserve flexible ramping capability into real-time markets. RTUC can commit short start units to create flexible ramping headroom, but the headroom is not a binding procurement. RTD will re-evaluate the ramping requirement, and bindingly award flexible ramping capability based on more accurate information. The 95% and 60% confidence levels mentioned in the proposal are illustrative. The ISO will perform statistical study using historical data to determine the requirements in day-ahead and real-time. All threshold values, penalty prices, and other parameter settings mentioned in the proposal are also tentative, and subject to changes in the ISO's parameter tuning process.

To simplify notation, through rest of the paper, we'll be formulating and discussing flexible ramping products in the context of enforcing a system wide requirement. However, the ISO may also enforce regional requirements if it is necessary to keep certain ramping flexibility in certain regions. If a regional flexible ramping requirement constraint is binding, the regional flexible ramping cost will be allocated in the corresponding region.

2. FLEXIBLE RAMPING PRODUCTS DESIGN

There are three characteristics that distinguish the flexible ramping products from other capacity products, such as ancillary services.

Fast ramping 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 capability can be fully utilized in one RTD interval when they are needed. In contrast, all ancillary services in the ISO are based on 10-minute ramping capability.

Dispatched in RTD on a regular basis Flexible ramping capability is continuously being dispatched in RTD to meet the energy imbalances. In contrast, regulation services are dispatched in real-time by AGC, and operating reserves are dispatched after major contingency happens. Day-ahead procured non-contingent spinning reserve may be dispatched in RTD, but only when there is over procurement. Flexible ramping products can improve the ISO's dispatch flexibility in RTD, while ancillary services cannot.

Capability preserved now to be used in the future Flexible ramping product is capability set aside now to be used in the future. Day-ahead procured flexible ramping is capability not used in IFM, and preserved into real-time markets. RTD procured flexible ramping is capability not used in the current RTD interval, and preserved into the next RTD interval. In contrast, ancillary services are capacities set aside for a trade interval, and to be deployed for the same trade interval if the condition to use them is triggered later.

Flexible ramping products will be modeled in IFM, RTUC, and RTD. The main purpose of modeling flexible ramping products in IFM is to make unit commitment decision for long start units, and award flexible ramping capability to preserve it into real-time markets. The commitment decisions for long start units and flexible ramping capability awards are binding in IFM. The purpose of modeling flexible ramping in RTUC is to make real-time unit commitment decisions, and to create flexible ramping headroom so that the system has sufficient flexible ramping capability. The real-time unit commitment decisions are binding for the first 15-minute interval in RTUC. Similar to energy dispatch, the flexible headroom is not binding in RTUC. It is better to procure flexible ramping capability in RTD than in RTUC because RTD runs closer to real-time, and thus has more accurate information. RTD will re-evaluate the flexible ramping requirement and bindingly procure flexible ramping capability based on more accurate information. The flexible ramping products awards will be compensated according to the marginal prices in the procurement processes (IFM and RTD).

[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.

2.1 FLEXIBLE RAMPING PRODUCTS BIDDING RULES

The market will accept separate capability bids on upward flexible ramping product and downward flexible ramping poduct, which express the resources' cost associated with providing such flexible ramping capability. The upward capability bid can be different from the downward capability bid. A resource must have an economic energy bid to back up the flexible ramping capability. If a resource does not have an explicit flexible ramping bid, it is assumed to have zero cost to provide flexible ramping.

A resource can provide flexible ramping as long as it has an economic energy bid. It does not need to have a certified flexible ramping capability. Undeliverable flexible ramping capability will be subject to no-pay settlement. In addition, the ISO has the right to check a resource's ramping rate, and disqualify the resource from providing flexible ramping if the actual ramping rate differs significantly from the submitted ramping rate.

2.1.1 FLEXIBLE RAMPING BID CAP AND FLOOR

Similar to ancillary services, a flexible ramping bid will only have one bid segment with bid cap equal to $250/MWh and bid floor equal to $0/MWh.

2.1.2 FLEXIBLE RAMPING SELF PROVISION

In the IFM, a Scheduling Coordinator (SC) can self provide flexible ramping capability. If an SC chooses to self provide upward flexible ramping capability, its real-time energy bid cannot exceed the minimum of two times its default energy bid and $300/MWh. If an SC chooses to self provide downward flexible ramping capability, its real-time energy bid cannot be lower than $0/MWh. This is to prevent an SC from self providing flexible ramping in IFM, and then bidding extreme prices for energy in real-time to get extreme energy payment for the flexible ramping capability.

There is no explicit self provision mechanism for flexible ramping in real-time markets. An SC 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 $0/MWh), it implies the marginal price of flexible ramping must be $0/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 in real-time markets.

2.1.3 FLEXIBLE RAMPING MARKET POWER MITIGATION

The ISO believes that the implicit flexible ramping offer, bid cap and requirement relaxation (discussed later) should adequately address the concern of market power. Therefore, the ISO will not propose a more sophisticated market power mitigation mechanism at this moment, but may do so if the need arises in the future.

2.1.4 FACTORING ENERGY COST INTO FLEXIBLE RAMPING COST

Because flexible ramping capacity is continuously being dispatched in RTD, energy cost should also be considered in the procurement process. Two resources with the same flexible ramping capability offer but different energy offers are not equally economic considering the possibility of energy dispatch in RTD. In other words, even the flexible ramping capability bids are the same, the resource with higher energy cost should have a higher overall cost anticipating a non-zero dispatch probability. It would be better if the procurement process could recognize the difference in expected energy cost, and give flexible ramping capability awards to the resource with lower overall cost.

A stochastic optimization can achieve this because the distribution of uncertainty is explicitly modeled so that the energy dispatch probability and cost can be accurately evaluated. However, as discussed earlier, the current technology does not allow solving stochastic programs that models uncertainties in detail in real-time markets, and that is why the flexible ramping products are created as a deterministic model to mimic a stochastic program. The expected energy cost can also be modeled in a simplified manner in the flexible ramping products to mimic a stochastic program.

The simplified method only factors in the expected energy cost when the energy bid is very high, say higher than $300/MWh, or very low, say lower than $0/MWh. Assume with extreme energy bids, a resource will not be dispatched under the normal conditions. By normal conditions, we mean the imbalances that can be covered by the flexible ramping capability. We have assumed the flexible ramping procurement target is to cover 95% confident level with 2.5% probability of the net load ramping up exceeding the upward flexible ramping requirement and 2.5% probability of the net load ramping down exceeding the downward flexible ramping requirement. Therefore, if the energy bid is higher than $300/MWh, the capability can only be dispatched when the upward 2.5% probability events happen; if the energy bid is lower than $0/MWh, the capability can only be dispatched for energy when the downward 2.5% probability events happen. This means the extreme energy cost will be incurred with 2.5% probability. Therefore, compared with the flexible ramping capability with energy bids $300/MWh, the flexible ramping capability with energy bids higher than $300/MWh has a higher expected energy dispatch cost in the amount of

2.5%*(energy bid (at the last upward flexible ramping MW) – 300).

This expected energy dispatch cost should be factored into the flexible ramping bid to properly evaluate the composite upward flexible ramping cost.

composite upward flexible ramp cost = upward flexible ramping bid +

0.5*(1 – confidence level)*max{energy bid (at the last upward flexible ramping MW) – 300, 0}.

The calculation means if the energy bid is higher than $300/MWh, then the upward flexible ramping cost will appear to be more expensive by (2.5%*energy bid) than a resource with energy bid below $300/MWh. The higher the energy bid, the harder the capability can be awarded upward flexible ramping.

Similarly,

composite downward flexible ramp cost = downward flexible ramping bid –

0.5*(1 – confidence level)*min{energy bid (at the last downward flexible ramping MW), 0}.

Note that the last downward flexible ramping MW is the bottom of the downward flexible ramping capability. The calculation means if the energy bid is lower than $0/MWh, then the downward flexible ramping cost will be more expensive by (–2.5%*energy bid) than a resource with energy bid higher than $0/MWh. The lower the energy bid, the difficult the capability can be awarded downward flexible ramping.

Factoring the energy cost at the last flexible ramping MW at 2.5% probability is an approximation of the expected energy cost. This only applies to resources who bid very high or very low. It provides a simple way to fairly compare the expected energy cost from different resources offering flexible ramping capability.

The flexible ramping capability marginal price may change with the flexible ramping cost being adjusted by energy bid. The composite price is only used in the procurement process. The original capability bid will be used in bid cost recovery.

2.1.5 LINKING DAY-AHEAD FLEXIBLE RAMPING AWARD AND REAL TIME ENERGY BID

The ISO is concerned that resources with day-ahead awards may have incentive to increase the energy bid in real-time to

- keep the day-ahead flexible ramping payment without really helping improve dispatch flexibility in RTD, or
- if the flexible ramping capability is needed in real-time, the dispatched energy can receive high energy price.

Stakeholders are aware of the concern, but also pointed out that resources may have different costs in the day-ahead market and the real-time market, so it is inappropriate to lock in the day-ahead bids.

To mitigate the concern and allow resources to have different bids in the day-ahead market and real-time market, the ISO proposes the following method. In the day-ahead market, a resource can specify the real-time energy bid range by a bid floor and bid cap. The resource specific bid cap will be used to calculate the composite upward flexible ramping cost, and resource specific bid floor will used to calculate the composite downward flexible ramping cost in the day-ahead market as discussed in section 2.1.4. In real-time market, the resource must bid within the bid range. A resource is motivated to accurately estimate the real-time bid in order to offer the real-time energy bid range in IFM properly. Offering the resource specific bid cap too high will reduce a resource's chance of being awarded upward flexible ramping, and offering the resource specific bid floor too low will reduce a resource's chance of being awarded downward flexible ramping. On the other hand, if the resource specific bid range is too narrow, it will restrain the real time energy bid. Therefore, a resource should evaluate the bid range accurately in order to get flexible ramping capability awards in IFM without inadvertently restraining the real-time bid.

2.2 CO-OPTIMIZING FLEXIBLE RAMPING PRODUCTS WITH ENERGY AND ANCILLARY SERVICES

This section will cover the stylized optimization model of co-optimizing the flexible ramping products with energy and ancillary services. The optimization model applies to IFM, RTUC and RTD. RTUC has one addition feature to allow interplay between day-ahead market and RTUC, which will be discussed in section 2.3.

In the IFM, the flexible ramping products will be modeled in each hour. The RTUC and RTD are both multi-interval look-ahead optimization. The flexible ramping products will be modeled in each interval of RTUC and RTD. Modeling flexible ramping products in advisory intervals enable the optimization foresee potential problems in the future, and take actions accordingly. As will be discussed later, the IFM procurement in all hours and RTD procurement in the binding interval are financially binding.

2.2.1 CO-OPTIMIZATION FORMULATION

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.

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

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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.

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.

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 $\lambda_t^{FRU} \cdot \sum_{i \in I_{FR}} FRU_{i,t}$.

2.2.2 REQUIREMENT RELAXATION

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. Ancillary services will be priced at price cap $250/MWh if any scarcity (requirement violation) happens. As discussed at the end of section 1, flexible ramping product does not have a fixed procurement target due to the random nature of variability and uncertainties. That is why the ISO proposes a penalty curve that functions like a demand curve. In other words, how much flexible ramping the ISO is willing to procure depends on the offer prices. If the offer prices are low, the ISO may procure more flexible ramping, and if the offer prices are high, the ISO may procure less flexible ramping. This is to make flexible ramping cost effective.

The ISO will use the following step penalty function:

- requirement violation from 0 MW to 100 MW, penalty price $100
- requirement violation from 100 MW to 200 MW, penalty price $150
- requirement violation from 200 MW to 300 MW, penalty price $200
- requirement violation above 300 MW, penalty price $250

The penalty prices are lower than the bid cap $250/MWh unless the violation is greater than 300 MW. The ISO may adjust the penalty prices based on experience, and may also use different penalty prices the day-ahead market and real-time market.

2.3 INTERPLAY BETWEEN DAY-AHEAD MARKET AND RTUC

RTUC 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 RTUC so that they can meet the RTUC requirement. This is consistent with how the ancillary services procured in day-ahead market are modeled in RTUC currently.

2.3.1 CONVERSION OF DAY-AHEAD AWARDS IN RTUC

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 RTUC. 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 5. The non-contingent non-spinning reserve awards in day-ahead that become online in RTUC 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.

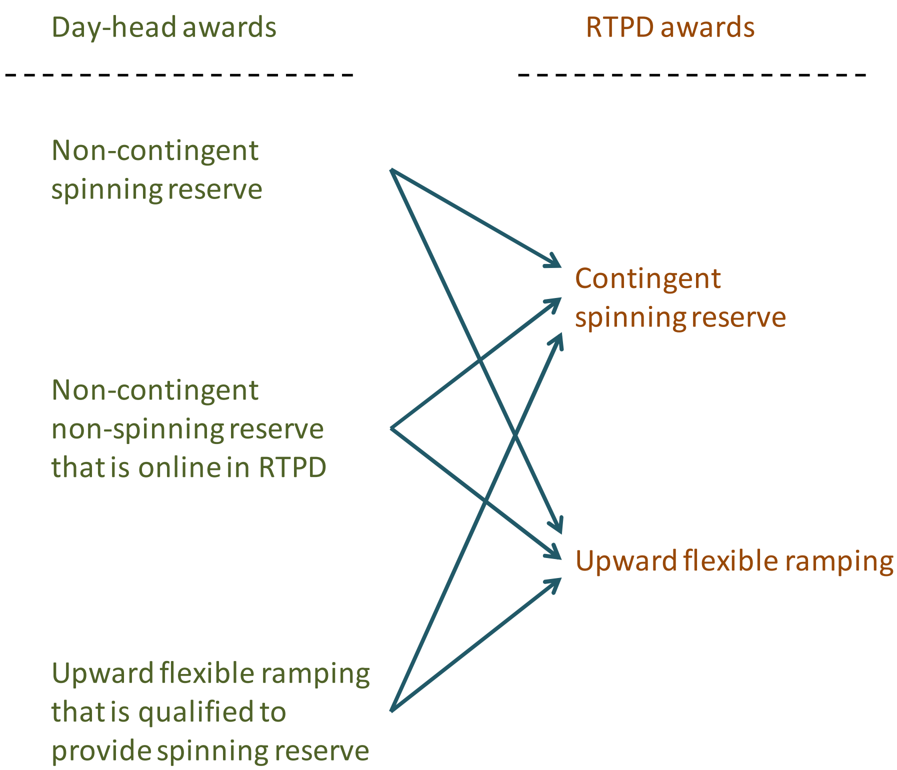

FIGURE 5: CONVERSIONS BETWEEN NON-CONTINGENT RESERVES AND UPWARD FLEXIBLE RAMPING PRODUCT IN RTUC

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 RTUC, and only applies to day-ahead awards. Basically, the conversion design allows RTUC to make a second decision about the capacity awarded in IFM. This is different from the ancillary service substitution where regulation-up can substitute spinning reserve, and spinning reserve can substitute non-spinning reserve. The differences between conversion and substitution will be discussed in detail in section 2.3.2.

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 RTUC. 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.

Conversion can be modeled in the following way. The day-ahead awards of non-contingent spinning reserve (also non-contingent non-spinning reserve that becomes online in RTUC) 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 RTUC. The sum of these two will be less than or equal to the corresponding day-ahead award

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

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

The upward flexible ramping, including the remaining day-ahead award $FRU_{i,t}^{REMAIN}$ and the portion being converted from day-ahead spinning reserve $FRU_{i,t}^{CONV}$, will be used to meet the upward flexible ramping requirement in RTUC. The spinning reserve, including the remaining day-ahead award $SP_{i,t}^{REMAIN}$ and the portion being converted from day-ahead upward flexible ramping award will be used to meet the spinning reserve requirement (cascading with regulation-up and non-spinning reserve) in RTUC. Note that the total upward flexible ramping headroom in RTUC 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 RTUC will be paid in day-ahead market at the day-ahead upward flexible ramping marginal price, and will be paid in RTUC at the difference between the spinning reserve marginal price and the flexible ramping marginal price, i.e. RTUC spinning reserve marginal price – RTUC 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 RTUC has been paid in day-ahead market at the day-ahead spinning reserve marginal price, and will not be paid in RTUC, 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.

Note that conversion is not a forced buy-back, and should not trigger no-pay charge.

2.3.2 CONVERSION VS SUBSTITUTION

We want to clarify that the two terms, substitution and conversion, have different meaning, and are not interchangeable.

Substitution is a term to describe the relationship between two products. Substitution needs to have a direction, such as product A is substitutable for product B. The substitution direction also implies the quality difference: product A is substitutable for product B means product A is of a higher quality than product B. There are two possible substitutions allowed in the ISO: regulation-up substituting spinning reserve, and spinning reserve substituting non-spinning reserve. These substitutions are allowed due to the quality difference in meeting the operational need: regulation-up is a better quality service than spinning reserve, and spinning reserve is a better quality service than non-spinning reserve. Substitution cannot be bi-directional. If product A is substitutable for product B, and product B is also substitutable for product A, they are of equal quality, and should be the same product.

At the beginning of Section 2, we discussed the differences between the flexible ramping products and the ancillary services. Due to these differences, flexible ramping products and ancillary services are not substitutable on a product basis.

Nonetheless, flexible ramping and non-contingent flagged spinning reserve may behave similarly sometimes. For example, when spinning reserve is over procured in day-ahead and some of the day-ahead non-contingent flagged spinning reserve may be dispatchable in RTD, and thus behaves like upward flexible ramping. In this case, it would benefit both the system and the resource to allow the day-ahead non-contingent spinning award to be used as flexible ramping.

The capacity that changes the purpose of usage from day-ahead to real-time, e.g. from day-ahead spinning reserve to real-time upward flexible ramping, is called a conversion. Basically, conversion allows the real-time optimization to make a second decision about the day-ahead awards. We stress that conversion does not apply on a product basis.

Conversions will improve market efficiency by allowing capacity to be used in the most valuable way. Some stakeholder argues that converting from upward flexible ramping to spinning reserve may harm the bidder, because the day-ahead flexible ramping bid may have included anticipated real-time energy revenue. In other words, the day-ahead flexible ramping bid would be higher if they know it is possible that the flexible ramping may be converted into spinning reserve. The ISO agrees that the flexible ramping cost would be different because the conversion changes the likelihood of energy dispatch. However, the ISO disagrees with the conclusion that the conversion may harm the bidder. The correct conclusion should be with the conversion, a resource should revaluate the energy dispatch likelihood plus the conversion likelihood to factor all these revenues into the flexible ramping bid. If a resource does this, the conversion cannot harm the resource.

Some stakeholders would like to use the spinning reserve bid for flexible ramping if the spinning reserve bid is lower. This can be achieved by imposing the bidding rule that upward flexible ramping cannot exceed spinning reserve bid, so the co-optimization will determine the best use of the capacity. However, the ISO stress that this does not mean non-contingent spinning reserve is substitutable for upward flexible ramping capability.

2.4 PROCURING FLEXIBLE RAMPING IN RTD

RTUC creates upward headroom $R^{FRU,RTUC}$ and downward headroom $R^{FRD,RTUC}$. The headroom is set to difference between the 95% confidence level of the most severe RTD net load among the three 5-minute RTD intervals and the expected RTUC net load.

In RTD, imbalance differences are realized in three 5-minute intervals. In each of the three 5-minute intervals, RTD will perform economic dispatch in response to realized imbalance for the current 5 minutes, and procure flexible ramping capability for the next 5 minutes based on most current information. The flexible ramping headroom created in RTUC may become RTD flexible ramping capability award, or become energy dispatch.

The RTD flexible ramping procurement target is calculated as follows:

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

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

The RTD upward flexible ramping procurement target is set to the minimum of two bounds. The first bound $NL_{t+1}^{RTUC} + R_{t+1}^{FRU,RTUC} - NL_t^{RTD}$ is the RTUC net load 95% confidence "roof" $NL_{t+1}^{RTUC} + R_{t+1}^{FRU,RTUC}$ (including both RTUC net load and the RTUC 95% confidence flexible ramping headroom) minus the current RTD interval t net load. 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. Note the difference between $R_t^{FRU,RTUC}$ and $R_t^{FRU,5min}$ is that the former captures how much net load can change from RTUC net load within 15 minutes, while the latter captures how much net load can change from the current RTD net load in 5 minutes. The RTD procurement target will be calculated in this way for every interval in the multi-interval optimization.

The RTD upward flexible ramping requirement calculation is illustrated in Figure 6. The data used to plot Figure 6 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.

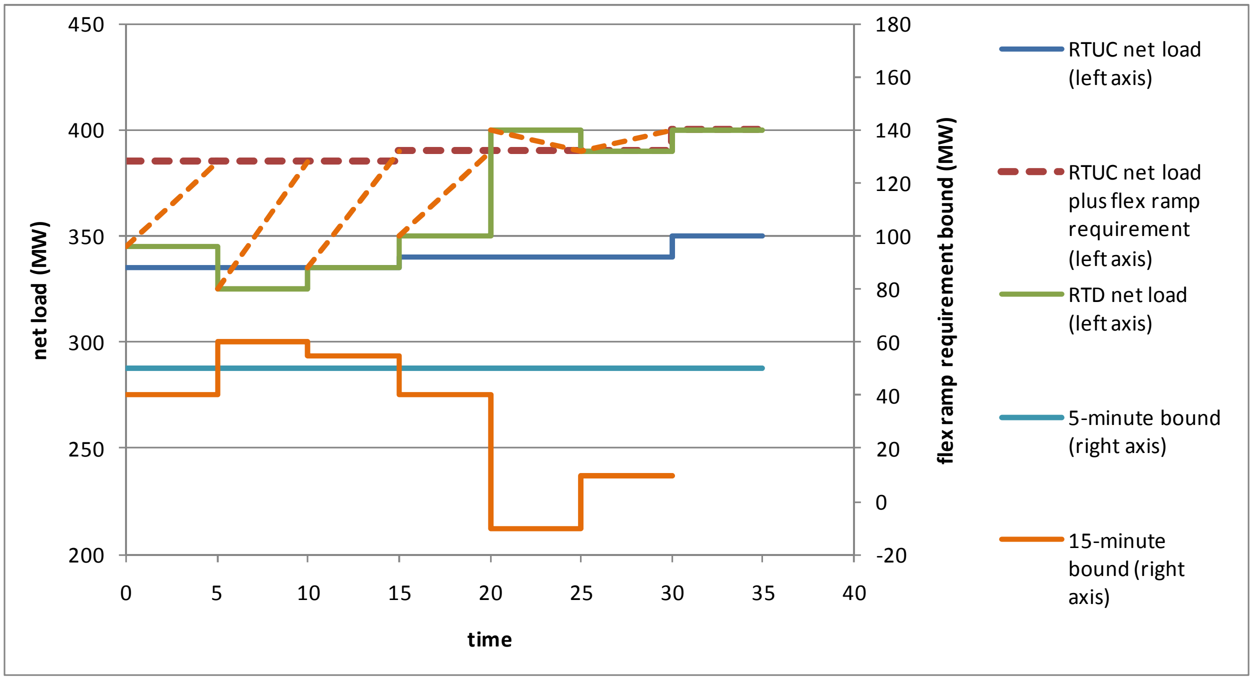

FIGURE 6: RTD UPWARD FLEXIBLE RAMPING REQUIREMENT

		RTUC1			RTUC2			RTUC3
		RTD1	RTD2	RTD3	RTD4	RTD5	RTD6	RTD7
	RTUC net load	335	335	335	340	340	340	350
	RTD net load	345	325	335	350	400	390	400
upward	RTUC 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	RTUC requirement	40	40	40	40	40	40	40
	15 minute bound	50	30	35	50	100	80	
	5 minute bound	40	40	40	40	40	40	40
	RTD requirement	40	30	35	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 RTUC 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 RTUC, then its remaining day-ahead award is 90 MW. If the resource has 60 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 93 MW of flexible ramping in RTD, it will receive the RTD flexible ramping payment for 93 – 90 = 3 MW.

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

- Because RTD has more accurate information than RTUC, the dispersion of imbalance is smaller, so the total procurement amount including both upward and downward should be less than RTUC.
- Flexible ramping capability can be procured from different resources in RTD, such that the resources that can provide flexible ramping in RTD are not limited to those that have headroom in RTUC.
- 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 concern about the flexible ramping opportunity cost in RTUC 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 a resource that is awarded flexible ramping in RTD indeed loses the opportunity of being dispatched for energy for the same RTD interval. The false opportunity cost issue will be discussed in more detail in section 2.5.1.

2.5 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

This section will summarize the flexible ramping product settlement, 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 RTUC will receive the difference between the RTUC spinning reserve price and the RTUC 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 flexible ramping price. If the RTD flexible ramping award is less than the day-ahead award (the amount remaining after RTUC 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 load lost, energy cost, and flexible ramping cost. If a resource self provides flexible ramping, then the resource is only allowed to recover flexible ramping cost above the self provision level. In other words, the ISO is not going to included either cost or revenue for self provided flexible ramping capacity in bid cost recovery calculation.

2.5.1 AVOID FALSE OPPORTUNITY PAYMENT

Flexible ramping is fast ramping capability preserved now to be used in the future. This characteristic is the key to answer the stakeholders' questions about the opportunity cost issue.

Resource capacity may be used to serve load now or be preserved to serve future load. Energy dispatch comes from capacity used to serve load now, while flexible ramping capability is capacity preserved for future use. Preserving some fast ramping capability for future use may benefit the system under the circumstances that the energy balance can be maintained now without relying on the fast ramping capability, and the capability may be crucial to maintain power balance for the future. Flexible ramping capability, whether procured in IFM or procured in RTD, has this characteristic. Day-ahead procured flexible ramping is capability preserved from being dispatched in the day-ahead market, so it can be dispatched in the real-time market. Therefore, if opportunity cost arises because the capability is economic in the day-ahead market, the resource should be paid the opportunity cost. Similarly, RTD procured flexible ramping is capability preserved from being dispatched in the current RTD interval, so it can be dispatched in the next RTD interval. Therefore, if opportunity cost arises because the capability is economic in the current RTD interval, the resource should be paid the opportunity cost. There is no conceptual level inconsistency between the day-ahead procured flexible ramping and real-time procured flexible ramping capability. It is incorrect to claim that flexible ramping procured in day-ahead is treated differently from flexible ramping procured in RTD.

Some stakeholders argue that the day-ahead procured flexible ramping is paid the capability price and then the real-time energy price if being dispatched, while the real-time procured flexible ramping is only paid the capability price, but not the real-time energy price. This is not the case. Flexible ramping capability procured in RTD cannot be dispatch for energy in the same interval that the flexible ramping is procured. Rather, it may be dispatched for energy in and only in the next RTD interval. Therefore, flexible ramping capability procured in RTD may also be paid the capability price and then the energy price. Regardless whether this happens or not, the payment does not constitute a false opportunity cost payment as will be discussed below.

Generally, it is not a problem for the same capacity to get both a capacity payment and an energy payment if it is dispatched as long as the capacity has a higher quality than just energy. For example, RUC capacity is paid both the capacity and the energy if it is dispatched. This is okay because the RUC capacity has a real-time must offer obligation and thus it is of higher quality than regular energy, which can choose to offer or not to offer into the real-time market. Similarly, the flexible ramping is a higher quality product because it can ramp fast. Therefore, flexible ramping should receive the capability payment, which captures the value of being fast. The difference between flexible ramping capability price and RUC capacity price is that the flexible ramping capability price may include opportunity costs, while RUC capacity price does not include opportunity costs. This is because by providing flexible ramping, which means preserve the capability for future use, may cause the resource to lose the opportunity of being dispatched now, and thus lose the energy profit. RUC capacity does not lose opportunity of any kind.

A comparison between RUC capacity and flexible ramping capability regarding in which market processes they are procured, compensated and dispatched is summarized in Table 2.

Capacity	Procurement time	Dispatch time	Possible energy lost opportunity	Price includes energy opportunity cost	False lost opportunity cost payment if the capacity is settled	Capacity settlement
RUC capacity	Day-ahead after IFM	Current RTD	No	No	No	Yes
DA flex ramp	In IFM	Current RTD	IFM	Yes	No	Yes
RTUC flex ramp	In RTUC	Current RTD	No	Yes	Yes	No
RTD flex ramp	In RTD	Next RTD	Current RTD	Yes	No	Yes

TABLE 2: COMPARING OPPORTUNITY COST OF FLEXIBLE RAMPING CAPABILITY AND RUC CAPACITY

RUC capacity is not co-optimized with any other products. As a result, RUC price does not include any opportunity cost. Therefore, RUC capacity does not have false opportunity cost issue. Flexible ramping capability procured in IFM and RTD also do not have false opportunity cost issue because preserving the capability does incur lost opportunity of earning the IFM energy payment. In IFM, if awarding flexible ramping capability causes the resource to lose the energy dispatch opportunity in IFM, we must compensate the resource for the opportunity cost. In RTD, if awarding flexible ramping capability causes the resource to lose the energy dispatch opportunity in the current RTD interval, we must also compensate the resource the opportunity cost. In contrast, if flexible ramping is procured in RTUC, because the energy dispatch is not binding in RTUC, and the corresponding RTD may dispatch the capability, it does not really incur a lost energy dispatch opportunity. Therefore, the resource should not be compensated for the opportunity cost in RTUC. That is why the ISO proposes not to settle flexible ramping capability in RTUC.

2.5.2 FLEXIBLE RAMPING NO PAY SETTLEMENT

Flexible ramping no-pay rules are similar to ancillary service no-pay rules. Flexible ramping products have a lower payment priority than ancillary services, so no pay charge will be applied to flexible ramping products first before it is applied to ancillary services. There are four major categories of no-pay including

- undispatchable capability,
- undelivered capability,
- unavailable capability, and
- unsynchronized capability.

Details about each of the categories will be discussed below.

A resource with flexible ramping awards is illustrated in Figure 7. Its flexible ramping awards under normal conditions should be within [Pmin, Pmax], and also be limited by 5-minute ramping capability. It exactly follows instruction, and there is no payment rescission in this case.

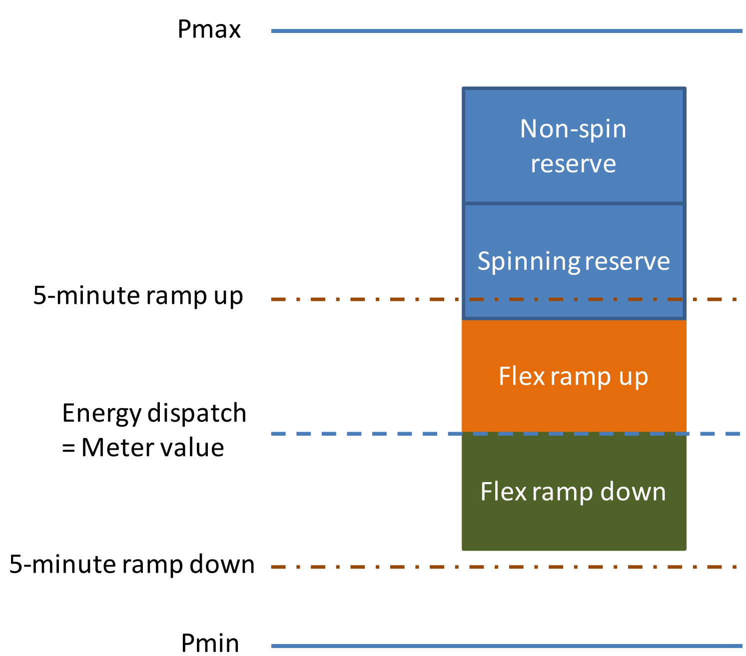

FIGURE 7: A RESOURCE WITH NO FLEXIBLE CAPCITY PAYMENT RECISSIONS

- **Undispatchable Capability** – There are two subcategories of Undispatchable Capability:
  - **Availability-Limited Capability** – If a resource's capability is re-rated in real-time, the total amount of flexible ramping Awards may not be available in Real-Time for dispatch due to the availability limitation. This is illustrated in Figure 8, where Pmin and Pmax are re-rated,

and cut into the flexible ramping awards. The capability that is cut off will be subject to no-pay.

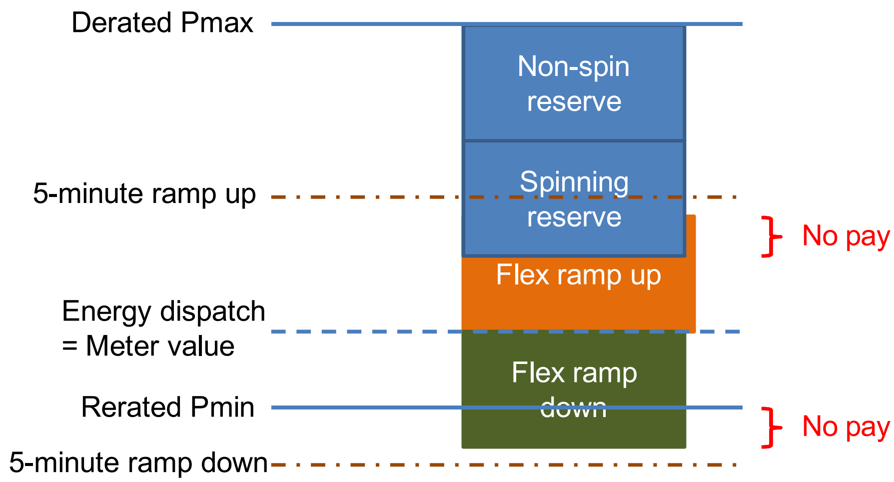

FIGURE 8: A RESOURCE WITH UNAVAILABLE FLEXIBLE RAMPING CAPABILITY NO PAY

- **Ramp-Limited Capability** – Flexible ramping are required to be delivered in 5 minutes. If a resource does not have the 5-minute Ramp Rate capability in Real-Time to deliver the flexible ramping awarded, then a portion of the flexible ramping capability is not available due to the Ramp Rate limitations on the resource. This is illustrated in Figure 9.

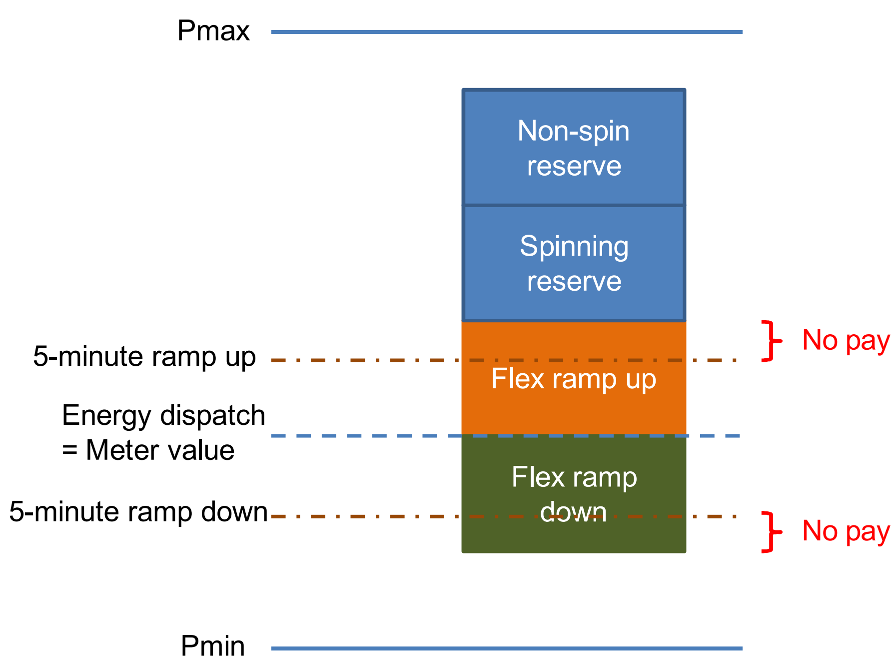

FIGURE 9: A RESOURCE WITH RAMP-LIMITED NO PAY

- **Undelivered Capability** – If a resource's flexible ramping award is dispatched for energy, the resource should follow instructions in order to fulfill the flexible ramping award. Otherwise, the flexible ramping awards may be subject to no pay charge calculated in the following way.

How close a resource follows instruction can be measured by its uninstructed energy, which equals the meter value minus the expected energy. Generators have a 10-minute meter value, while the flexible ramping award is dispatched every 5 minutes. Undelivered capacity calculation needs a 5-minute meter value. A 5-minute meter value can be calculated proportional to the expected energy in the two 5-minute intervals of a 10-minute meter value. Denote a RTD interval t as a ramp-up interval for a resource if the resource's energy dispatch increases in the next 5-minute interval, i.e. expected energy (t+5) > expected energy (t). Similarly, denote a RTD interval t as a ramp-down interval for a resource if the resource's energy dispatch decreases in the next 5-minute interval, i.e. expected energy (t+5) < expected energy (t). For a ramp-up interval t, if the uninstructed energy is negative in interval t+5, denoted by UIE^{-}, then the resource's upward flexible ramping award in interval t is undelivered by UIE^{-}. Similarly, for a ramp-down interval t, if the uninstructed energy is positive in interval t+5, denoted by UIE_5^{+}, then the resource's flexible downward ramping award in interval t is undelivered by UIE^{+}. Undelivered flexible ramping capacity, as measured by UIE_5^{+} and UIE_5^{-}, will be subject to no-pay charge. For a resource with both day-ahead award and real-time award, the no pay MW will be prorated.

Example: Resource A has 100 MW day-ahead upward flexible ramping award, and 50MW real-time upward flexible ramping award. In one ramp-up interval, $UIE^{-} = 15$ MW. In this case, 10 MW from day-ahead award and 5 MW from real-time award will be subject to no pay charge.

- **Unavailable Capability** – No Pay charges apply when flexible ramping capability is unavailable because it is converted to energy without dispatch instructions from the ISO. Uninstructed Deviations in Real-Time may cause flexible ramping capability to be unavailable to the ISO.

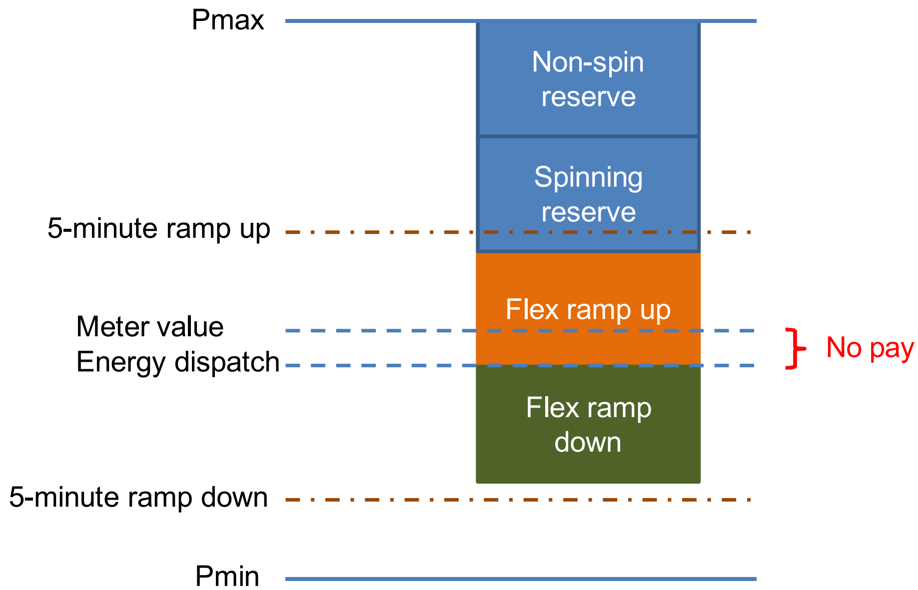

FIGURE 10: A RESOURCE WITH UNAVAILABLE CAPABILITY NO PAY

- **Unsynchronized Capability** – A resource's flexible ramping award will be subject to no pay if the resource does not comply with the synchronization standards.

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 3, in which only non-zero values are shown. The day-ahead market prices are listed in Table 4. 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 RTUC 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 3: 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 4: DAY-AHEAD MARKET PRICES

3.2 RTUC MARKET

Now consider the RTUC market with the day-ahead awards listed in Table 3. For simplicity, consider only one interval in RTUC 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 RTUC 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 RTUC 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 5 and Table 6. Note that in Table 5, "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 5: RTUC 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 6: GENERATOR OPERATING LIMITS AND RAMP RATES

Given the system requirements, the optimal RTUC schedules of energy, ancillary services and flexible ramping products are listed in Table 7, and the corresponding marginal prices are listed in Table 8.

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 7: RTUC 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 8: RTUC 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 RTUC. 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 2.3.1, 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 8, 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 RTUC, but will be re-evaluated in RTD.

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

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 9, 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 10.

		RTUC1			RTUC2			RTUC3
		RTD1	RTD2	RTD3	RTD4	RTD5	RTD6	RTD7
	RTUC net load	335	335	335	340	340	340	350
	RTD net load	345	325	335	350	400	390	400
upward	RTUC 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	RTUC 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 9: RTD DISPATCH AND FLEXIBLE RAMPING AWARD

Product	Marginal Price ($/MWh)
Energy	49
Upward flexible ramping product	3.3
Downward flexible ramping product	4

TABLE 10: 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 incremental 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 11: 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 implemented for current ancillary services.

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

The ISO has applied the cost allocation guiding principles described in the draft final proposal that was posted on March 15th [7]in developing the cost allocation straw proposal for the flexible ramping product. The cost allocation guiding principles have seven elements: (1) Causation, (2) Comparable Treatment, (3) Accurate Price Signals, (4) Incentivize Behavior, (5) Manageable, (6) Synchronized, and (7) Rational.

The ISO proposes to allocate the costs for the flexible ramping product based upon deviations (gross positive deviations and gross negative deviations at the resource level) that are aligned with setting the procurement target. The expectation of potential deviations across all market participants causes the ISO to procure the flexible ramping product.

The ISO proposes to allow updated expected delivery profiles to be used for a resource's baseline to measure deviations as needed. The profiles will be used by market participants to shape their hourly schedules for the purposes of determining their flexible ramping product cost allocation. The profiles will not be used for the settlement of imbalance energy. The purpose is to allow supply resources to establish a baseline that is aligned with the flexible ramping procurement decision. The profile will provide a baseline that is more relevant to the impact on the flexible ramping product procurement requirement for the purpose of determining the cost allocation of the flexible ramping products.

5.1 PROPOSED DEVIATION BASELINE FOR FLEXIBLE RAMPING PRODUCT

The ISO proposes to allocate the costs for the flexible ramping product based upon deviations that are aligned with setting the procurement target. The expectation of potential deviations across all market participants results in the procurement of the flexible ramping product. When flexible ramping products are procured at the system level, the totally system variability and uncertainty between RTPD and RTD is the driver of the procurement target. There may be instances where on average two market participants offset the other's deviations which decreases the overall system requirement. This offsetting impact decreases the quantity of the flexible ramping product the ISO must procure and is reflected in a lower system procurement target. Consistent with the Accurate Price Signals guiding principle the ISO has proposed a measurement of the billing determinant that reflects the expectation of a resource's impact on the flexible ramping product procurement.

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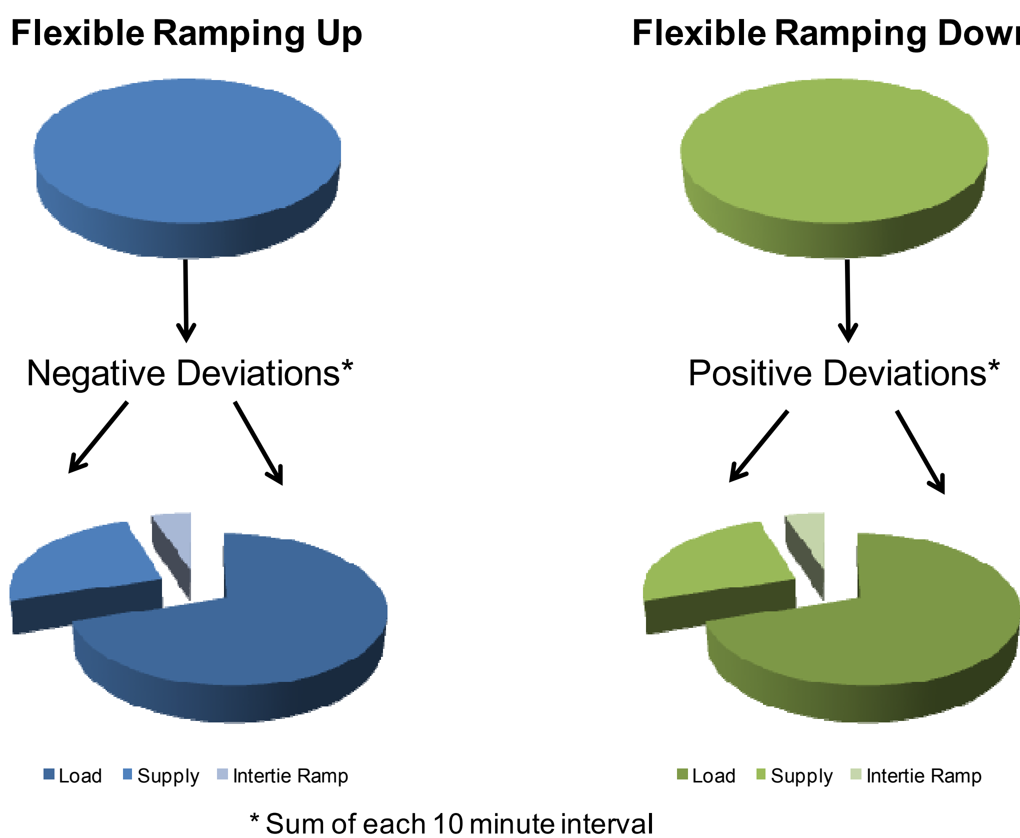
[7] Additional information on the cost allocation guiding principles can be found at http://www.caiso.com/informed/Pages/StakeholderProcesses/CostAllocationGuidingPrinciples.aspx

The flexible ramping cost is the product of the procurement target and the market clearing price paid to suppliers of the flexible ramping product. The costs include capacity procured in both the day-ahead and real-time market. The flexible ramping product costs are represented by the blue (Up) and green (Down) pies in Figure 11.

In order to allocate the costs to scheduling coordinators, the ISO plans to develop a comparable method to calculate deviations across supply and demand resources. The upward flexible ramping product is procured to address variability and uncertainty that is observed as negative deviations to system conditions assumed in RTPD. The downward flexible ramping product is procured to address variability and uncertainty that is observed as positive deviations to system conditions assumed in RTPD.

In stakeholder comments, several market participants suggested that deviations across all supply resources should be netted prior determining the initial division of system wide costs. By netting across all supply resources, the net deviations for this category will be comparable with the load category which nets deviations across all load serving entities. The ISO agrees and is now proposing to initially net load, net supply and net intertie ramps across resources for the initial division of flexible ramping costs. The ISO will then utilize the gross deviations within each category to allocate the costs to individual resources.

FIGURE 11 - FLEXIBLE RAMPING PRODUCT COST ALLOCATION



5.2 NEW BASELINE TO MEASURE DEVIATIONS

In order to be consistent with the Comparable Treatment guiding principle, a similar baseline from which to measure deviations for the purposes of allocating the flexible ramping costs is being proposed. The ISO proposes to allow updated expected delivery profiles to be used for resources as needed. The profiles will be used by market participants to set a baseline for the purposes of determining their flexible ramping product cost allocation based upon deviations to the profile. The profiles will not be used for the settlement of imbalance in energy. The profile is aligned with the flexible ramping procurement decision. The profile will provide a baseline that is more relevant to the impact on the flexible ramping product procurement requirement for the purpose of determining the cost allocation of the flexible ramping products.

Those resources that require a profile will submit the profile 37.5 minutes prior to the start of "binding" RTPD interval where units are committed to provide the flexible ramping product. The scheduling coordinator will provide a two hour profile of expected output; however, only the first 15 minute interval will set the baseline for measuring deviations subject to the flexible ramping cost allocation and be "binding" for determining the flexible ramping product cost allocation. The scheduling coordinator is allowed to provide an updated profile every 15 minutes. For example, assume it is 08:22:30 AM, the scheduling coordinator submits the resource's profile for 9:00 to 10:00 as follows: 9:00-9:15 = 10 MWh, 9:15-9:30 = 20 MWh, 9:30-9:45 = 30 MWh, 9:45-10:00 = 40 MWh, 10:00-11:00 = 50 MWh. The baseline for determining deviations from the baseline in the 9:00-9:15 interval would be 10 MWh and the other intervals will be advisory. Then at 08:37:30 AM, the scheduling coordinator submits the profile for 9:15 to 10:15 as follows: 9:15-9:30 = 15 MWh, 9:30-9:45 = 25 MWh, 9:45-10:00 = 40 MWh, 10:00-10:15 = 50 MWh, 10:15-11:15 = 55 MWh. The baseline for determining deviations in the 9:15-9:30 interval would be 15 MWh even though in the profile previously submitted the advisory amount for the second interval was 20 MWh.

The deviations will be calculated for each 10 minute settlement interval based upon the rolling 15 minute forecasts. The 15 minute baselines will be converted to 10 minute intervals to align with the metering of internal generation. For example, assume two RTPD intervals. Interval 1 the forecast is 15 MWh and interval 2 the forecast is 30 MWh. The baseline for the 10 minute settlement interval 1 is 10 MWh, settlement interval 2 is 15 MWh, and settlement interval 3 is 20 MWh.

Table 12 below summarizes by resources type how the profile, baseline, actual output and deviation will be measured for allocating flexible ramping product costs. Additional discussion on each of the elements is discussed in Sections 5.2.1 to 5.2.4. The profile is in 15 minute intervals in order to align with unit commitment within RTPD and is then converted to 10 minutes in order to align with metering and settlement intervals.

TABLE 12 - SUMMARY OF DEVIATION CALCULATIONS

		Profile	Baseline	Actual	Deviation	Allocation
1	Load	ISO 15 Minute Forecast	Convert Profile to 10 Min	ISO 10 Minute Observed Demand	Baseline - Actual	Load ratio share
2	Variable Energy Resource	Resource's 15 Minute Forecast	Convert Profile to 10 Min	10 Minute Meter	Baseline - Actual	Gross Deviation
	Internal Generation	N/A	Dispatch	10 Minute Meter	UIE1 + UIE2	Gross UIE
	Interties Operational Adjustments	N/A	N/A	Deemed Delivered	OA1 + OA2	Gross OA
3	Interties Ramp	20 Minute Ramp Modeled	Convert Profile to 10 Min	Assumed Delivered	Baseline - Actual	Gross SC Deviation

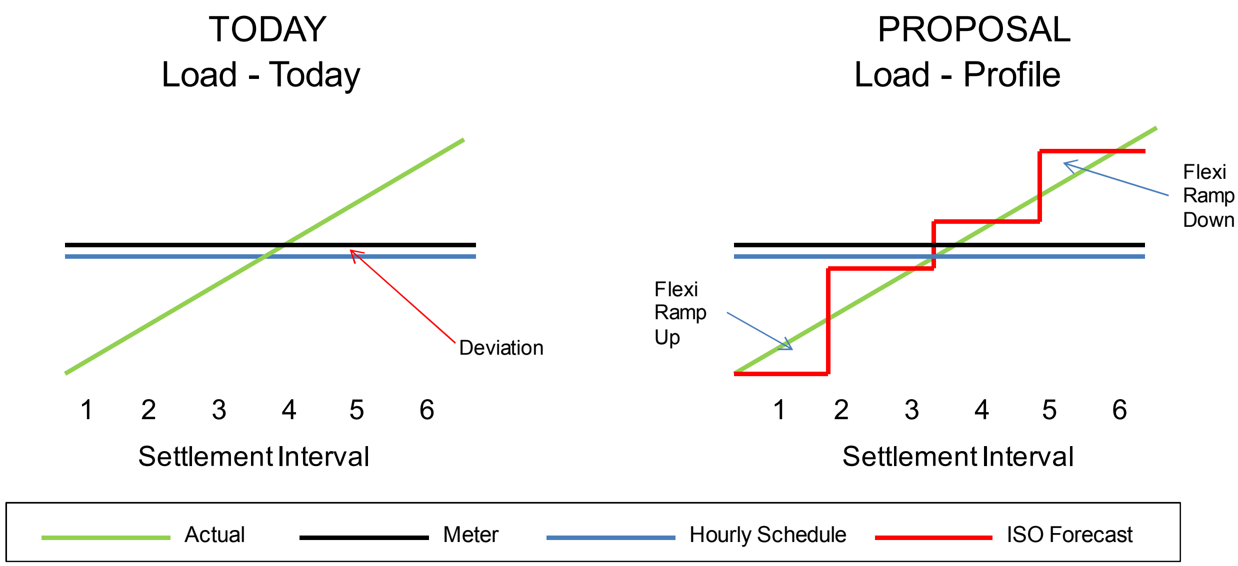
The ISO reiterates that the initial split of costs to categories 1, 2, and 3 above will net across all resources within the category. The ISO will then utilize the gross deviations by resources within each category to allocate the costs for that category.

5.2.1 PROFILE FOR LOAD

In the real-time market, Load does not submit economic bids or schedules. The ISO commits resources in RTPD to meet the CAISO forecast of CAISO demand (CFCD). The real-time forecast of demand used for RTPD has 15 minute granularity. While metering of Load for energy settlement purposes is done on an hourly basis, the ISO can measure system demand with more granularly based upon actual observations. The ISO proposes to use the ISO RTPD demand forecast as the hourly profile to calculate the baseline for measuring Load deviations. The ISO updates the Load forecast for RTPD every 15 minutes. The ISO will use the forecast for the "binding" RTPD interval to compare to observed demand to calculate the system wide positive and negative deviations that will be used to allocated flexible ramping costs attributable to Load.

Figure 12 below illustrates why the RTPD forecast of load is a more accurate calculation of deviations to be used for allocation of flexible ramping product costs. Using current deviation metrics, the comparison of the hourly meter value to the hourly schedule does not reflect the actual dispatch capability necessary to manage the variability and uncertainty observed. However, the profile more accurately measures the uncertainty and variability that resulted between the RTPD load forecast and actual load.

FIGURE 12 - COMPARISON OF BASELINE TO CALCULATE DEVIATIONS



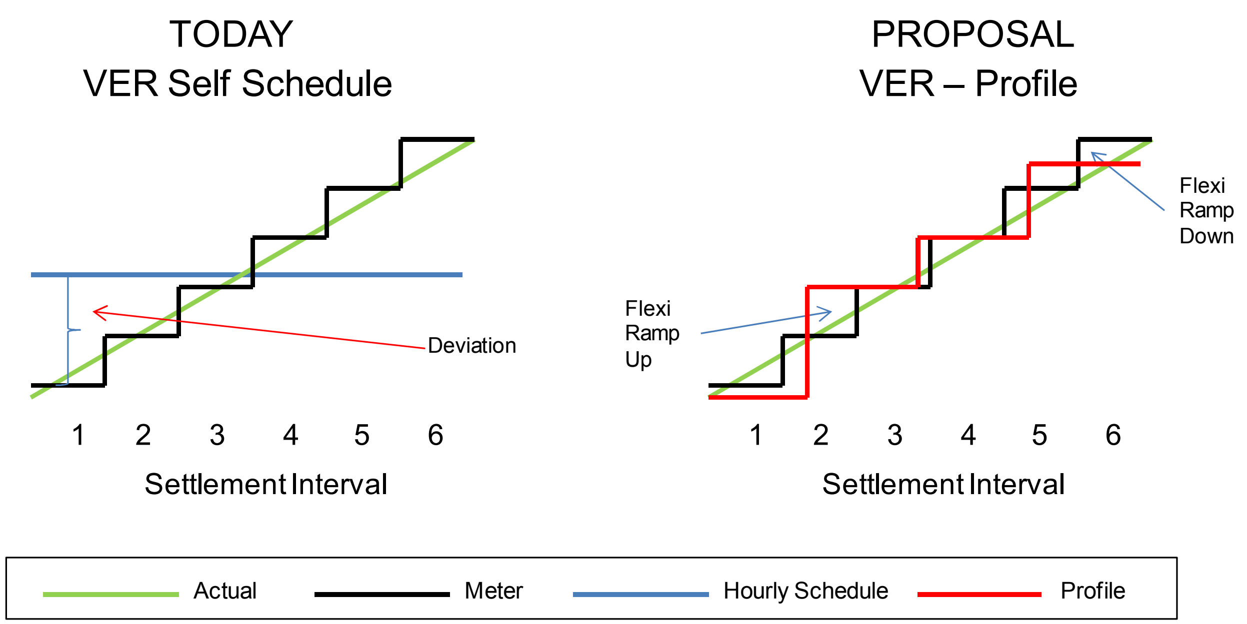
Since the ISO is not requiring more granular metering of load by load serving entities, the deviations will be used to determine the share of flexible ramping costs attributable to load. The costs will then be allocated based upon load ratio share. In order to allocate costs more precisely, load serving entities would need to provide metering at 10 minute granularity to align with internal generation metering. If a load serving entity uses 10 minute metering, such as load following metered sub-systems, then the load serving entity could submit its own load profile and its cost allocation would be calculated similar to section 5.2.2.

5.2.2 PROFILE FOR VARIABLE ENERGY RESOURCES

Currently the participating intermittent resource program (PIRP) requires resources to submit the ISO provided hourly forecast as a real-time self schedule in order to be eligible for monthly netting of imbalance energy. The ISO proposes to allow the scheduling coordinator of variable energy resources (both PIRP and non-PIRP) or other resources as needed to submit a profile of their output. The profile is submitted 37.5 minutes prior to the "binding" RTPD interval. Every 15 minutes, the resource can submit an updated profile which will be used as the baseline for the next "binding" RTPD interval.

As Figure 13 below illustrates, under the current measurement of uninstructed deviations the beginning and ending energy settlement intervals overstate the deviations that drive procurement of the flexible ramping product in RTPD. However, with the profile, the 15 minute granularity aligns measurement of deviations with the RTPD timeframe of the flexible ramping procurement decision. Since the profile submitted is better aligned with actual output and the 10 minute settlement interval, the resource would be allocated a more accurate portion of flexible ramping product costs. Scheduling coordinators for variable energy resources will be incentivized to improve the resource's profile in order to reduce the flexible ramping product cost allocation, consistent with the Incentivizing Behavior cost allocation guiding principle. Allowing updates every 15 minutes of the profiles results in comparable treatment between variable energy resources with real-time self schedules and conventional generation. If a variable energy resource does not submit a profile, the ISO will based deviations on current calculations of uninstructed imbalance energy equivalent to conventional generation,

FIGURE 13 - COMPARISON OF BASELINE TO CALCULATE DEVIATIONS



The ISO is considering leveraging functionality that is being implemented within the Dynamic Transfers initiative. In the Dynamic Transfers initiative, renewable resources can submit updates using 5 minute granularity for their future output profile. If a scheduling coordinator provides 5 minute granularity for a resource, the ISO will use the simple average of the three relevant 5 minute intervals to create the 15 minute profile used to calculate flexible ramping product cost allocation deviations.

Over time, the ISO will utilize the profiles submitted by variable resources to refine the procurement target for flexible ramping up and flexible ramping down. This is consistent with the Cost Causation, Incentivizing Behavior and Manageable guiding principles.

5.2.3 INTERNAL GENERATION PROFILE

The ISO models conventional internal generation's ramp between hourly day-ahead schedules to determine uninstructed imbalance energy; therefore, the profile for flexible ramping cost allocation does not need to be submitted by the resource. The ISO has two types of uninstructed imbalance energy. Uninstructed imbalance energy 1 (UIE1) measures a resource's deviations up to its five minute dispatch over the 10 minute settlement interval. If a resource deviates greater than the 5 minute dispatch, the remaining deviation is measured as uninstructed imbalance energy 2 (UIE2). The flexible ramping products are procured for generation which has deviated from both its hourly schedule and ISO dispatch. If a resource deviates from the ISO dispatch, the subsequent RTD interval will dispatch other internal generation to make up the shortfall. As a result, UIE1 and UIE2 will be counted towards the allocation of flexible ramping costs because other resources will have to be dispatched to address those deviations.

5.2.4 IMPORT AND EXPORT HOURLY PROFILE

Static hourly schedules for Imports and Exports allow a twenty minute ramp for hourly schedule changes. When a static hourly import schedule increases, the ISO must have sufficient upward and downward ramping capability for the final two RTD intervals from internal generation to respond to dispatches to allow the import schedule increase. Then in the subsequent hour, the ISO must have sufficient downward and upward ramping capability for the first two RTD intervals from internal generation able to respond to dispatches while the import reaches its hourly schedule. Since a scheduling coordinator can have both imports and exports in a given hour, the calculation of the MWh subject to flexible ramping cost allocation will be calculated based upon the scheduling coordinators net import and export position between hours.

Table 13 below shows the calculation of the flexible ramping up and flexible ramping down initial system allocation. The example assumes that total system intertie ramps from 4000MW in HE01 to 4500MW in HE02. A spreadsheet has been posted for this example.

TABLE 13 – CALCULATION OF DEVIATION FOR 500MW INTERTIE RAMP BETWEEN HE01 AND HE02

	HE01						HE02					
	RTPD 3			RTPD 4			RTPD 1			RTPD 2		
	1000.00			1041.67			1083.33			1125.00		
	RTD 7	RTD 8	RTD 9	RTD 10	RTD 11	RTD 12	RTD 1	RTD 2	RTD 3	RTD 4	RTD 5	RTD 6
Baseline	333.33	333.33	333.33	347.22	347.22	347.22	361.11	361.11	361.11	375.00	375.00	375.00
Deemed Delivered	333.33	333.33	333.33	333.33	338.54	348.96	359.38	369.79	375.00	375.00	375.00	375.00
	Settlement 4		Settlement 5		Settlement 6		Settlement 1		Settlement 2		Settlement 3	
Baseline	666.67		680.56		694.44		722.22		736.11		750.00	
Deemed Delivered	666.67		666.67		687.50		729.17		750.00		750.00	
Flexi-Ramp Up Allocation	0.00		13.89		8.68		1.74		0.00		0.00	
Flexi-Ramp Down Allocation	0.00		0.00		1.74		8.68		13.89		0.00	

In addition, 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 (OA1 and OA2). Operational adjustments are similar to deviations from internal generation hourly schedules (UIE1 and UIE2) which results in the need for additional flexible ramping procurement. The operational adjustments for both imports and exports are included in the supply allocation (See category 2 in Table 12).

5.3 COST ALLOCATION IF REGIONAL PROCUREMENT

The cost allocation discussion has assumed a system wide procurement of the flexible ramping product. If in the future, the ISO moves to regional procurement of flexible ramping products, the cost allocation approach outlined in this draft final proposal is still applicable. The initial allocation to the three categories will be based upon the costs incurred in the defined regions. Then resources within the defined region will be allocated their portion of the appropriate category based upon their gross deviations.

5.4 COST ALLOCATION GRANULARITY WITHIN DAY

Several stakeholders commented that the costs of flexible ramping products may be different by hour. Therefore resources which deviate in specific hours with high flexible ramping product procurement costs should receive a higher relative cost allocation. For example, a solar resource will not deviate during the night as its output will be zero, but using daily granularity this is not reflected in its flexible ramping product cost allocation. The ISO is proposing to segment the day to respond to stakeholder input, but is not proposing hourly level granularity as this may lead to the need to implement a two-tiered allocation due to insufficient deviations. If a resource does not have any deviations over the course of a month, the ISO would not procure flexible ramping products as its expected deviation are very low.

The day will be segmented in to four flexible ramping cost allocation rates: day 12:00-18:00, night 00:00-06:00, morning ramp 06:00-12:00, and evening ramp 18:00-24:00. The granularity proposed will result in different cost allocation based upon when a resource deviates assuming there are difference on an hourly basis of the cost to procure the flexible ramping product. In addition, the number of deviations in a given segment should not necessitate a two-tier allocation because of insufficient deviations within a given six hour time period. The proposed daily segments may be adjusted in the future based upon empirical data after the flexible ramping product has been implemented.

5.5 MONTHLY RE-SETTLEMENT

Since the flexible ramping products are 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. Consistent with the Synchronization guiding principle, the ISO proposes to re-settle costs based upon the monthly rate per deviation. The monthly rate will be determined by the total costs incurred during the month divided by the sum of positive (or negative for flexible ramping product up) deviations across all resources. On a daily basis, scheduling coordinators will be allocated flexible ramping product costs as a share of their resources deviations. At the end of the month, these daily charges will be reversed, and the resource will be charge the monthly rate for each of its deviations in the appropriate daily segment (day, night, morning ramp, and evening ramp).

5.6 ASSIGNMENT OF FLEXIBLE RAMPING COST ALLOCATION

The flexible ramping costs will be allocated to scheduling coordinators. In order to facilitate implementation of bilateral contracts, the ISO will implement functionality to allow assigning of the flexible ramping product cost allocation at the resource level.

6. PLAN FOR STAKEHOLDER ENGAGEMENT

Item	Date
Post Third Revised Straw Proposal	March 7, 2012
Stakeholder Conference Call	March 14, 2012
Stakeholder Comments Due	March 21, 2012
Post Flexible Ramping Product Design Draft Final Proposal (together with Cost Allocation Draft Final Proposal)	April 9, 2012
Stakeholder Meeting	April 16, 2012
Stakeholder Comments Due	April 24, 2012
Board Meeting	May 16, 2012

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*

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

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

NL_t^{RTD} net load in RTD interval t

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 RTUC

$FRU_{i,t}^{DA}$ 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 RTUC 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 RTUC, $MT = 5$ for RTD

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

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.[8] 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,[9] 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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[8] 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.

[9] 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[10] 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.

$$\sum_{i \in I_{FR}} FRU_{i,t} \geq R_t^{FRU}$$

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

$$\sum_{i \in I_{FR}} FRD_{i,t} \geq R_t^{FRD}$$

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

APPENDIX C: MODELING ANCILLARY SERVICES WITH OPERATIONAL RAMP RATE

Ramp rate typically has the unit MW/minute. Currently, ancillary services are modeled with fixed ancillary service ramp rate specific to the AS type. Regulation services (reg-up and reg-down) are modeled with regulation ramp rate, and operating reserves (spinning reserve and non-spinning reserve) are modeled with operating reserve ramp rate. For each AS product, the award amount cannot exceed 10 times the specific AS ramp rate as the ancillary services are 10-minute deliverable.

The fixed AS ramp rate is a simplified model for co-optimizing energy and ancillary services in the ISO markets. However, the real deliverable generation is governed by the operational ramp rate, which is a function of the generation output level. Therefore, the AS procurement based on AS ramp rate may over-estimate or under-estimate the real ramping capability depending on the generation output level. The ISO has been considering using the operational ramp rate solely to determine the AS procurement, and published a Technical Bulletin to discuss this[11].

With the flexible ramping products being modeled with operational ramp rate, it is advantageous to completely replace the AS ramp rate with operational ramp rate in the market optimization because

- Using operational ramp rate for AS involves the same development effort as doing it for flexible ramping products. Therefore, combining the development is a cost effective approach.
- The flexible ramping products and AS are co-optimized. It is important to model them in a consistent way. Inconsistency in ramp rate modeling may result in sub-optimal solutions.

However, we stress that the implementation of flexible ramping product is not be contingent upon the effort of using operational ramp rate for ancillary services.

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[11] See CAISO Technical Bulletin "Dynamic Ramp Rate in Ancillary Service Procurement," http://www.caiso.com/Documents/TechnicalBulletin-DynamicRampRate_AncillaryServiceProcurement.pdf, May 2011.