Flexible Ramping Products

Incorporating FMM and EIM

Revised Straw Proposal

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1. INTRODUCTION

This paper describes the ISO's market design proposal for 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 challenges of maintaining power balance in the real-time dispatch. The ISO has observed that the fleet of units determined in the real-time unit commitment process (RTUC), also known as the real-time pre-dispatch (RTPD) process, sometimes is not positioned with sufficient ramping capability and flexibility in real-time dispatch (RTD) to handle the 5-minute to 5-minute system load and supply changes. 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, there are at least three undesirable outcomes:

- The system has to rely on regulation services to resolve the issue in real-time after the imbalance has caused frequency deviation or area control error (ACE)
- When power balance is violated, the RTD energy price is not priced by economic bids, but by administrative penalty prices, which creates market inefficiency in the long run. Moreover, the imbalance energy of resources providing regulation services is priced using the administrative penalty prices from RTD.
- If there is insufficient regulation service, the result of insufficient ramping capability is leaning on the interconnection, which may affect the ability to meet required operational performance criteria.

Since the new nodal market was implemented in 2009, the ISO has had a multi-interval optimization in the unit commitment and dispatch process. The multi-interval optimization can look several intervals ahead to meet forecasted ramping needs. The ISO has observed that the optimization will often create the exact amount of ramping capacity according to the imbalance forecast. When the future system condition materializes, the actual ramping need may differ from the forecast. If the actual ramping need is higher than the forecast, the net supply cannot meet the net demand, and a power balance violation is triggered. This happens because this is no margin of error between the interval ramping needs in a multi-interval optimization, and any deviation beyond the forecasted ramping need. The purpose of the flexible ramping products is to create ramping margin on top of the forecasted between interval ramping need, and thus reduce the frequency of spurious power balance violations. The flexible ramping products will compensate resources based upon the marginal opportunity cost from out of merit dispatch in the financially binding market interval.

2. CHANGES FROM PRIOR PAPER

- In the day-ahead market, the bid price for all resources is set at $0.00. Scheduling coordinators can enter a zero MW bid to prevent the resource from being awarded flexible ramping products in the day-ahead market.

- Modified the day-ahead market must offer obligation for resource capacity used to meet flexible capacity resource adequacy requirements. Resources with resource adequacy flexible capacity must bid a MW quantity in IFM greater than or equal to its amount of resource adequacy flexible capacity.

- Added a forward looking approach to establish price points on flexible ramping product demand curve.
- Provided more detailed discussion on the process for setting flexible ramping requirements in the IFM, FMM and RTD.
- Clarified the settlement of energy resulting from re-dispatch necessary to support a flexible ramping award. This energy will be settled at the LMP, unlike ramping energy which is settled at bid.
- Modified treatment of modeled ramps in RTD resulting from real-time unit commitment and economically bid 15-minute market import/exports in determining the flexible ramping requirement and cost allocation.
- Added additional cost allocation discussion of the monthly resettlement process, included day-ahead procurement costs from ISO resources in cost allocation of EIM constraints, and developed rule if initial hourly cost allocation to categories cannot be made.
- Minor editing and formatting changes.

3. BACKGROUND

With increasing levels of variable energy resources and behind the meter generation, the operational challenge of ramping capability is even more prominent, as the variable outputs of the renewable resources may increase the magnitude of the 5-minute to 5-minute net load changes. In Figure 1, the net load equals the load minus the renewable resources' total output. As shown in Figure 1, the 5-minute to 5-minute net load change may triple its magnitude in hour-ending 18 and 19 with renewable generation output moving in the opposite direction of load. It may also reverse the direction of load ramping in hour-ending 7 and 8.

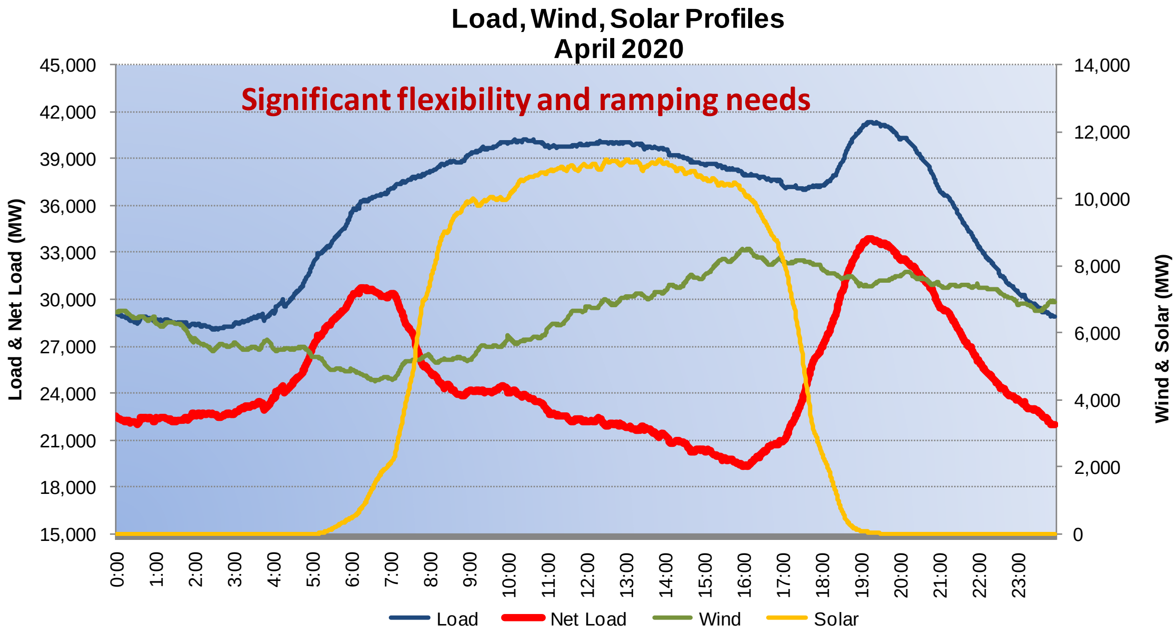

FIGURE 1: PROJECETED LOAD AND RENEWABLE PROFILES IN APRIL 2020[1]

Stakeholders have questioned why the ISO needs to design a new ramping product while regulation services are standard products to deal with the forecast uncertainties. Based on the timing that uncertainties are realized, there are two types of uncertainties: one is realized before the binding RTD dispatch, and the other is realized after the binding RTD dispatch. Moreover, uncertainties realized before the binding RTD dispatch have an impact on the RTD energy price in the binding RTD interval, while uncertainties realized after the binding RTD dispatch will not impact the RTD energy price. Regulation services are the standard products to take care of uncertainties realized after the binding RTD dispatch. Energy produced by regulation services will be compensated at the corresponding RTD energy price. From an operational point of view, more regulation procurement can also handle uncertainties realized before the binding RTD dispatch. However, from a market efficiency point of view, procuring more regulation is problematic. On the one hand, some uncertainties are already realized in RTD and create the ramping need. On the other hand, more capacity is locked in as regulation service and cannot be dispatched in RTD. This will lead to more power balance violations in RTD and as a result RTD prices are set by administrative penalty prices. In addition, when regulation services are dispatched, they will be paid the RTD prices, so if more regulation is procured to handle uncertainties, the additional dispatched energy will be compensated at the administrative penalty prices even when there is no actual operational issue, but just an artificial power balance issue in RTD. That is why it is inappropriate to procure more regulation services to deal with the uncertainties that are realized before the binding RTD dispatch. The flexible ramping products address uncertainties realized before the binding RTD dispatch. Flexible ramping procurement and deployment will also influence the energy prices to best reflect the system conditions.

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[1] Operating flexibility analysis for R.12-03-014, Mark Rothleder, Shucheng Liu, and Clyde Loutan, CPUC workshop, June 4, 2012.

Stakeholders have also questioned whether procuring more non-contingent spinning reserve would be able to achieve what the flexible ramping product is addressing. The problem with procuring more non-contingent reserves and dispatching them in RTD is the false opportunity cost payment. When spinning reserve is procured, its price already includes the energy opportunity cost. If the capacity is dispatched in RTD, then the resource will also receive the energy payment. Therefore, the same capacity will be compensated twice for the energy profit. We expect the ramping capacity will be procured and deployed very frequently, so using non-contingent spinning reserve for this purpose is problematic from the due to the double compensation.

Prior to these market-based full flexible ramping products, the ISO has implemented a flexible ramping constraint to address certain reliability and operational issues observed in the ISO's operation of the grid.[2] Upon the completion of the Flexible Ramping Constraint stakeholder process, the ISO Board of Governors agreed with stakeholder and the ISO that greater market efficiency can be gained by developing market-based products that allow for the identification, commoditization and compensation for the needed flexible capability.

The flexible ramping product will help the system to maintain and use dispatchable flexibility. The flexible ramping product is the 5-minute ramping capability commodity, which will be dispatched to meet 5-minute to 5-minute net system demand changes, or net system movement, in RTD. The net system demand is defined as the load plus export minus all resources' schedules that are not 5-minute dispatchable, which may include renewable resources, imports, and self schedules. We will refer to the potential 5-minute to 5-minute net system movement in RTD as the Real Ramping Need. The Real Ramping Need is illustrated in Figure 2. Assume the current time is t–7.5 minutes, and the ISO is running RTD for the binding interval t (the 5-minute interval from t to t+5). From the market point of view, RTD interval t's net system demand is certain in the sense that it is not subject to future change in the market. However, the RTD net system demand for the advisory interval t+5 (the 5-minute interval from t+5 to t+10) is still subject to change in the future (from t–7.5 to t–2.5). Therefore, we view RTD advisory interval t+5's net system demand as a random variable with a spread from a lower limit to an upper limit. The lower limit and upper limit are illustrated in Figure 2. The purpose of the flexible ramping products is to be able to cover the random net system demand in interval t+5 with a spread from the lower limit to the upper limit. Note that the spread from the lower limit to the upper limit only reflects the ISO's intended coverage of the next interval's net system demand, and may not necessarily be able to cover all possible net system demand levels that may be realized when interval t+5 becomes the binding interval. The flexible ramping capability is met with separate products in the upward and downward directions as the ramp needs may be in both directions. The Real Ramping Need is

- Upward: max{ [upper limit at t+5] – [RTD net system demand at t], 0 }
- Downward: max{ [RTD net system demand at t] – [lower limit at t+5], 0 }

Note that the actual net system demand may be different from the RTD energy binding interval load, and the difference is covered by regulation services.

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[2] 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

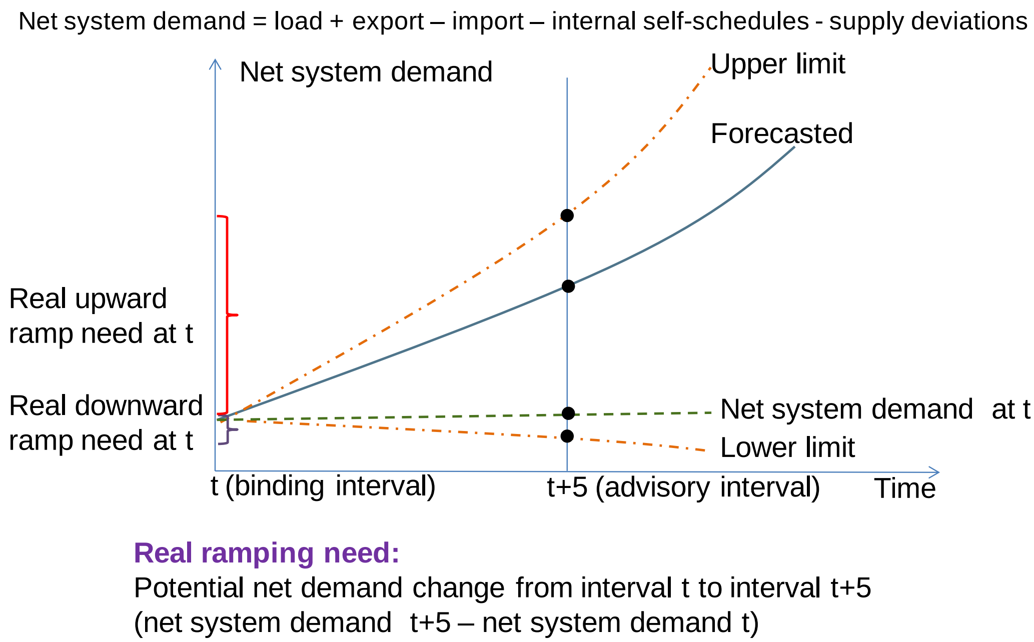

FIGURE 2: REAL RAMPING NEED

Stakeholders have questioned why the procurement target is real ramping need, not the unexpected ramping need on top of the expected ramping. The argument is that we should not compensate the resources that meet the expected ramping, and should only compensate resources that meet unexpected ramping. As discussed by the Market Surveillance Committee[3], there is no operational difference between resources that meet expected ramping and resources that meet unexpected ramping, and there may be resources in either category that are dispatched out of merit to provide flexible ramping capability. It is inappropriate to treat and compensate the resources under the two categories differently.

Stakeholders also questioned why cycling of generation resources are not considered in the flexible ramping day-ahead procurement. In the October 19, 2012 Market Surveillance Committee meeting, the MSC commented that this specific question can be generalized to the fundamental question whether energy market should have a mileage type of payment. The fundamental question can only be address in a much broader redesign of the energy market, and is out of the scope of the flexible ramping product initiative.

At the initial flexible ramping product implementation stage, the product is going to be procured for system wide need. However, the ISO is also considering enforcing regional requirements in the future if it is beneficial to distribute ramping capability across the footprint. If a regional flexible ramping requirement constraint is binding, the regional flexible ramping cost will be allocated at the system level.

[3] Scott Harvey, Flexi Ramp Product Design Issues, http://www.caiso.com/Documents/FlexiRampProductDesignIssues-MSCPresentation.pdf

4. FLEXIBLE RAMPING PRODUCTS DESIGN

In this section, we will cover the flexible ramping product design. The discussion will be focused on real-time markets because the product purpose is to improve real-time market dispatch flexibility. With the introduction of the new fifteen-minute market, the energy schedule from enforcing flexible ramping requirement during RTUC will be financially binding. This is beneficial because the opportunity cost of out of merit dispatch is actually realized by resources providing flexible ramping products in RTUC. The ISO also proposes to procure some of the ramping capability in the day-ahead market. One benefit of modeling flexible ramping products in the day-ahead market is to make unit commitment decision for long start units and establish forward financial position for flexible ramping capability.

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

Capability preserved for between interval changes: All ancillary services in the ISO's market are "standby" capacity in the sense that they are unloaded capacity to meet net system demand deviations from assumed level in the same interval. In contrast, the flexible ramping product is the only market product targeting at between interval net system demand changes.

Regularly dispatched in RTD: The flexible ramping product is 5-minute ramping capability, which is continuously procured and dispatched in RTD, to meet the net system movement. No similar capacity product exists in the ISO's current market. Regulation services are dispatched after RTD by Automatic Generation Control, not through economic bids. Operating reserves are dispatched through the real-time contingency dispatch only after a defined contingency event occurs. Flexible ramping products can improve the ISO's dispatch flexibility in RTD, while ancillary services reduce the RTD dispatch flexibility with some of the flexibility being locked in the ancillary service awards.

The flexible ramping product will be modeled as ramping capability constraints. Modeling flexible ramping in RTUC helps real-time unit commitment make the correct decisions in creating ramping headroom if it is necessary. The real-time unit commitment decisions are binding if such decisions cannot be revisited in later runs due to physical commitment time constraints. With the introduction of the fifteen-minute market, both the flexible headroom and energy schedules in RTUC are financially binding. The ISO will also procure flexible ramping capability in RTD and awards will be compensated according to the marginal prices in RTD where the energy awards are also financially binding.

4.1 FLEXIBLE RAMPING PRODUCTS BIDDING RULES

A resource can provide flexible ramping as long as it is RTD dispatchable and has an economic energy bid. It does not need to have a certified flexible ramping capability. The ISO has the right to check a resource's ramp rate, and disqualify the resource from providing flexible ramping if the actual ramping rate differs significantly from the submitted ramping rate. The ISO will only award flexible ramping products to RTD dispatchable resources (5-minute) that are able to offer energy into the real-time market. The flexible ramping product price will be based on marginal opportunity cost.

In the IFM, resources can bid a MW quantity for the flexible ramping product but the ISO will set the bid price at $0.00. The ISO has not been able to identify incremental marginal costs beyond those already imbedded within the energy bid price; however, the ISO does agree that a resource should be able to limit the MW quantity it can be awarded in IFM since an award will require the resource to bid into the real-time market or be subject to no-pay for not delivering the flexible ramping products.

Allowing scheduling coordinators to establish the maximum MW quantity to be awarded in the IFM addresses three stakeholder concerns:

1. The need to opt out of the flexible ramping product because the resource wants to be economically scheduled in day-ahead, but does not want those hourly schedules changed by the real-time market,
2. The potential for opportunity costs from sales outside the ISO market for capacity not subject to resource adequacy bidding rules after the IFM has cleared, and
3. Limits the flexible ramping award amount so that system RA commitments can be met through ancillary services awards when the energy bid curve exceeds the flexible resource adequacy capacity.

Resources must bid a MW quantity equal to or greater than the amount of their capacity used to meet their monthly resource adequacy flexible capacity requirements less the resource's Pmin. These bids must be submitted for the same hours as the resource's obligation under the resource adequacy flexible capacity rules.

A resource's flexible resource adequacy capacity is based upon the amount a resource can ramp over three hours and may include the Pmin of the resource, depending on its start-up time. The Pmin is subtracted from the capacity used to meet their resource adequacy flexible ramping requirement because unit commitment to Pmin can only occur in RTUC, it cannot be used to meet RTD ramping requirements. Therefore, the resource adequacy flexible capacity minus the resource's Pmin is the minimum MW quantity of flexible ramping products that must be offered in IFM. The minimum MW quantity will be inserted for both the flexible ramping up and flexible ramping down based upon the monthly flexible resource adequacy showing of the resource. The ISO will update the MasterFile each month with the minimum MW offer quantity for IFM. The ISO will generate a flexible ramping MW bid if an energy schedule is submitted. Scheduling coordinators can submit a flexible ramping MW bid higher than the minimum requirement.

Capacity bids (price and MW) for flexible ramping products are not allowed in the fifteen-minute market or RTD, because any operational cost for providing the ramping capability is foregone when the resource offers energy into the real-time market. The entire bid range submitted in the real-time market is available for the flexible ramping products.

4.1.1 FLEXIBLE RAMPING SELF PROVISION

Self provision for flexible ramping will NOT be supported in the ISO's market. Self providing downward flexible ramping will force the ISO to take the energy schedule in order to support the self provision no matter how high the energy offer price may be. This creates undesirable gaming opportunity for market participants. Self providing upward flexible ramping will make it difficult to dispatch the resource's economic capacity. The resource engaging in this activity effectively withholds its capacity without triggering the ISO's local market power mitigation. This again creates a market power concern, especially in local congested areas. Due to these reasons, the ISO will not support self providing flexible ramping.

4.1.2 FLEXIBLE RAMPING MARKET POWER MITIGATION

The ISO believes that the real-time pure opportunity cost pricing, the day-ahead implicit flexible ramping offer from economic energy offers, and flexible ramping demand curve (discussed later) should adequately address the concern of market power given the current volume of procurement. Therefore, the ISO will not propose any market power mitigation mechanism at this stage.

4.2 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 stylized model is for illustration purpose only, and may not reflect the actual implementation model. The optimization model applies to both RTUC and RTD. RTUC and RTD are both multi-interval look-ahead optimization. The flexible ramping products will be modeled by enforcing ramping constraints in each interval of RTUC and RTD.[4] Modeling flexible ramping products in advisory intervals enables the optimization to foresee potential problems in the future, and take actions accordingly. Under the FERC Order No. 764 market design changes implemented on May 1, 2014, the second fifteen-minute interval of the RTUC is the fifteen-minute market (FMM).

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.

Upward ramping capability limit: This constraint ensures that a resource's upward ramping award plus the total amount of upward reserves (regulation-up, spinning, and non-spinning) awards does not exceed its upward ramping capability over the market clearing interval.

Downward ramping capability limit: This constraint ensures that a resource's downward ramping award plus the regulation-down award does not exceed its downward ramping capability over the market clearing interval.

[4] The interaction between RTUC and RTD will not be discussed in detail in this paper. We will discuss this topic in the 08/14/2012 Market Surveillance committee meeting.

[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.

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.

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

The flexible ramping product is 5-minute ramping capability based on the dispatch level and the resource's ramp rate. The day-ahead market, RTUC and RTD have different market clearing interval granularity:

- Day-ahead market has 60-minute market clearing interval,
- RTUC has 15-minute market clearing interval, and
- RTD has 5-minute market clearing interval.

In the optimization, we will model the average 5-minute ramping capability over the market clearing interval. The ramping capability over the market clearing interval will be converted to the average 5-minute ramping capability by dividing it by an averaging factor AF (AF = 12 for day-ahead, AF = 3 for RTUC, and AF=1 for RTD). For example, if resource A has 60 MW capacity and 1 MW/minute ramp rate, it can be awarded 60 MW ramping capability over an hour. This can be converted to an average of 5 MW 5-minute ramping capability. In real-time markets, the difference between the FMM flexible ramping award and the DA 15 MW award will be settled at the FMM flexible ramping price. The difference between the FMM 5 MW award will be settled at the RTD flexible ramping price. For example, if the resource is awarded 4 MW 5-minute ramping capability in RTD, the resource has to pay back the 1 MW at the RTD flexible ramping price. Consider another resource B with the same capacity 60 MW, but a faster ramp rate of 10 MW/minute. In day-ahead market, resource would also be awarded 5 MW 5-minute ramping capability for each 5-minute interval in the hour. This is because evaluated on an hourly basis, there is no difference between the two resources' ramping capability. In FMM, resource A can still provide at most 5 MW 5-minute ramping capability, but resource B can provide 20 MW 5-minute ramping capability. In RTD, resource A can still provide at most 5 MW 5-minute ramping capability, but resource B can provide at most 50 MW 5-minute ramping capability. The more ramping capability from a fast resource is recognized in real-time markets with more granular level of ramping evaluation.

4.3 FLEXIBLE RAMPING REQUIREMENT IN RTD, FMM, IFM

As illustrated in Figure 2, in the financially binding 5-minute interval the market optimization will ensure that there is sufficient ramping capability available to meet the forecasted net load for interval T+5 and the upper limit and lower limit based upon forecast error. The market will calculate the forecast error by comparing the actual net load the market uses in the next RTD run when that interval becomes the financially binding interval with the net load it used when the interval was the T+5 interval. The market will use the forecast error to calculate the upper and lower limits of flexible ramping products that it will procure based upon the demand curve discussed in section 4.4. The minimum requirement it will procure is based upon the net load forecast used in market optimization for the advisory intervals.

The following methodology will be used to determine the flexibility requirements:

a) Develop a 5-minute granular forecast of gross load, wind/solar production and hourly interchange schedules. The model will also have the capability to exclude variable energy resources that submit economic bids from this step and consider them separately since they can be dispatched in RTD.
b) Determine the resource specific 5-minute ramps that result from RTUC that will be modeled in RTD such as unit start-up/shutdown and multi-stage generation transitions. This also includes the 10-minute ramp from 15-minute economically scheduled imports/exports.
c) Determine a 5-minute RTD imbalance requirement by netting the gross load forecast by the wind/solar production forecasts, hourly interchange schedules and excluding the generation and 15-minute intertie modeled ramps in RTD.
d) Develop a series of 5-minute RTD imbalance requirement by introducing forecast error uncertainty based on historical forecast error pattern for each 5-minute interval of the day. The ISO proposes to use a rolling 30 days, with adjustments for weekends and holidays, to evaluate historical advisory RTD imbalance requirement error pattern. The look back period will be configurable.
e) Develop a distribution of the changes in the 5-minute RTD imbalance requirement by calculating the difference between the advisory RTD imbalance requirement at time (t+5 minute) by the binding RTD imbalance requirement at time (t) for each 5-minute interval of the day.
f) Analyze the distribution of changes in 5-minute RTD imbalance requirement and identify the +/-X% confidence level of the distribution for each 5-minute interval of the day. The ISO has proposed a 90%-95% confidence level as the appropriate level for establishing the upper and lower limits of the flexible ramping requirement.
g) The above process is performed individually for each BAA and in aggregate for the combined EIM footprint.
h) In the financially binding interval of RTD, the flexible ramping up total requirement will be equal to the upper limit less the RTD imbalance energy in the binding interval, but cannot be less than zero. Assuming the total up requirement is positive, the minimum requirement is the RTD imbalance energy in the advisory interval less the RTD imbalance energy in the binding interval. The demand curve requirement is the upper limit less RTD imbalance energy in the advisory interval.
i) In the financially binding interval of RTD, the flexible ramping down total requirement will be equal to the RTD imbalance energy in the binding interval less the lower limit, but cannot be less than zero. Assuming the total down requirement is positive, the minimum requirement is the RTD imbalance energy in the binding interval less the RTD imbalance energy in the advisory interval. The demand curve requirement is the RTD imbalance energy in the advisory interval less the lower limit.
j) For the purpose of procurement on a 15-minute basis in FMM, the entire requirement will be met through a demand curve. The maximum upper limit from the relevant three 5-minute intervals less the average 5-minute RTD imbalance energy from the prior 15-minute

interval will establish the total flexible ramping up requirement. The average 5-minute RTD imbalance energy from the prior 15-minute interval less the minimum lower limit from the relevant three 5-minute intervals establish the total flexible ramping down requirement. Since the ISO load forecast is used in FMM and not bid in demand, the same approach as outlined in step h) and i) will split the total requirement between the minimum requirement and demand curve requirement.

k) For the purpose of procurement on a hourly basis in IFM, the entire requirement will be met through a demand curve. The maximum upper limit from the relevant twelve 5-minute intervals less the average 5-minute RTD imbalance energy from the prior hour will establish the flexible ramping up requirement. The average 5-minute RTD imbalance energy from the prior hour less the minimum lower limit from the relevant twelve 5-minute intervals establish the flexible ramping down requirement.

4.4 CALCULATION OF DEMAND CURVE

The minimum requirement for flexible ramping is the expected net system movement between the binding energy interval and the next advisory interval if the net system demand is moving in the same direction of the ramping need. Otherwise, the ramping requirement is zero. For example, in RTD hour ending 18 interval 2, the advisory interval net system demand change from the energy binding interval is 30 MW, then the minimum upward flexible ramping requirement is 30 MW, and the minimum downward flexible ramping requirement is 0 MW. This is illustrated in Figure 3 and Figure 4. The penalty price for violating the minimum requirement is $247 which is slightly lower than the contingency reserve penalty price of $250.

The minimum requirement and the maximum requirement are connected by a demand curve that specifies several price levels and corresponding flexible ramping demand quantities. The demand curve applies to the ramp need on top of the expected ramp, a.k.a. unexpected ramp need, up to the maximum requirement. The demand curve will drive the unexpected ramp procurement according to flexible ramping supply price. Generally speaking, if the supply price is low, the unexpected ramp procurement amount will be more. If the supply price is high, the unexpected ramp procurement amount will be less. The unexpected procurement amount will be limited between the minimum requirement and the maximum requirement.

The demand curve is derived by estimating the marginal value of flexible ramping product. In estimating the marginal value of the flexible ramping product, we consider the benefit of reducing power balance violation frequencies in RTD.

This method relies on the following inputs:

- The distribution of net load $\widetilde{NL}_{t+5}$, or equivalently the destruction of $\widetilde{NL}_{t+5} - NL_{t+5}^{forecast}$
- The penalties of power balance violations

The distribution of net load is developed based on historical observations. From the distribution of net load, we also know the distribution of power balance violations. The distribution of positive power balance violation (PPBC) conditional on no flex ramp is the same distribution of net load exceeding net load forecast.

E(PPBC_penalty_cost|FRU=0) =

sum$_y$[prob($\widetilde{NL}_{t+5} = y$)*max($y - NL_{t+5}^{forecast}$, 0)*PPBC_penalty($y - NL_{t+5}^{forecast}$)].

If we assume x MW of flex ramp would reduce x MW of positive power balance violation, then the distribution of positive power balance violation conditional on FRU=x is the same distribution of net load exceeding net load forecast by x.

E(PPBC_penalty_cost|FRU=x) =

sum$_y$[prob($\widetilde{NL}_{t+5} = y$)*(max($y - NL_{t+5}^{forecast} - x$, 0)*PPBC_penalty($y - NL_{t+5}^{forecast} - x$)].

Now if we set a step size Δx for the FCR demand curve, the FRU demand price is

- [E(PBC_penalty_cost|FRU=0) – E(PBC_penalty_cost|FRC=Δx)]/Δx from 0 to Δx
- [E(PBC_penalty_cost|FRU=Δx) – E(PBC_penalty_cost|FRC=2Δx)]/Δx from Δx to 2Δx
- [E(PBC_penalty_cost|FRU=2Δx) – E(PBC_penalty_cost|FRC=3Δx)]/Δx from 2Δx to 3Δx

and so on.

We can also calculate the FRD demand price in the same way.

Now let's look at an example. Assume we use $1000 for positive power balance violation and –$150 for negative power balance violation as shown in Table 1. The net load distribution based on historical observations is listed in Table 2.

Power balance violation	Penalty
–200-0 MW	–$150
0-400 MW	$1000/MWh

TABLE 1: POWER BALANCE VIOLATION PENALTIES

$\widetilde{NL}_{t+5} - NL_{t+5}^{forecast}$	Distribution	
	Prob.	Avg. MW
–200-–100 MW	1%	–150
–100-0MW	2%	–50
0-100 MW	1%	50
100-200 MW	0.8%	150
200-300 MW	0.6%	250
300-400 MW	0.5%	350

TABLE 2: NET LOAD PROBABILITY DISTRIBUTION

First, we calculated the expected positive PBC penalty cost conditional on difference levels of FRU:

- E(PPBC_penalty_cost|FRU=0) = 0.01*50*1000 + 0.008*150*1000 + 0.006*250*1000 + 0.005*350*1000 = 4950
- E(PPBC_penalty_cost|FRU=100) = 0.008*50*1000 + 0.006*150*1000 + 0.005*250*1000 = 2550
- E(PPBC_penalty_cost|FRU=200) = 0.006*50*1000 + 0.005*150*1000 = 1050
- E(PPBC_penalty_cost|FRU=300) = 0.005*50*1000 = 250
- E(PPBC_penalty_cost|FRU=400) = 0

For step size 100 MW,

- from 0 to 100 MW, the FRU demand price is (4950–2550)/100 = $24
- from 100 to 200 MW, the FRU demand price is (2550–1050)/100 = $15
- from 200 to 300 MW, the FRU demand price is (1050–250)/100 = $8
- from 300 to 400 MW, the FRU demand price is (250–0)/100 = $2.5
- above 400 MW, the FRU demand price is $0.

We can also calculate the expected negative PBC (NPBC) penalty cost conditional on difference levels of FRD:

- E(NPBC_penalty_cost|FRD=0) = 0.02*(–50)*(–150) + 0.01*(–150)*(–150) = 375
- E(NPBC_penalty_cost|FRD=100) = 0.01*(–50)*(–150) = 75
- E(NPBC_penalty_cost|FRD=200) = 0

For step size 100 MW,

- from 0 to 100 MW, the FRD demand price is (375–75)/100 = $3
- from 100 to 200 MW, the FRD demand price is (75–0)/100 = $0.75
- above 200 MW, the FRD demand price is $0

A complete flexible ramping requirement setting consists of

- The minimum requirement set to the expected net system demand change in the same direction of the ramping need (equal to zero if the expected net system demand change is in the opposite direction of the ramping need)

- The demand curve starting from the minimum requirement

- The maximum requirement set to the 95% confidence interval (2.5% percentile of net system demand change for downward direction and 97.5% percentile of the net system demand change for the upward direction) to truncate the demand curve

An upward flexible ramping requirement curve is illustrated in Figure 3 by the solid line. Note that the expected upward net system demand ramp changes interval by interval, and this will shift the demand curve. However, the maximum requirement is independent of the expected upward net system movement, and will not be shifted. The higher the expected net load is, at any given price, the higher the demand for flexible ramping will be. If the net system movement is in the downward direction, the expected upward net system movement is negative. In this case, the requirement curve needs to be truncated at zero MW. This is illustrated in Figure 4. If the expected net load is in the opposite direction of the ramp need, then at any given price, the demand for flexible ramping will be less than or equal to the demand when the expected net load is in the same direction of the ramp need.

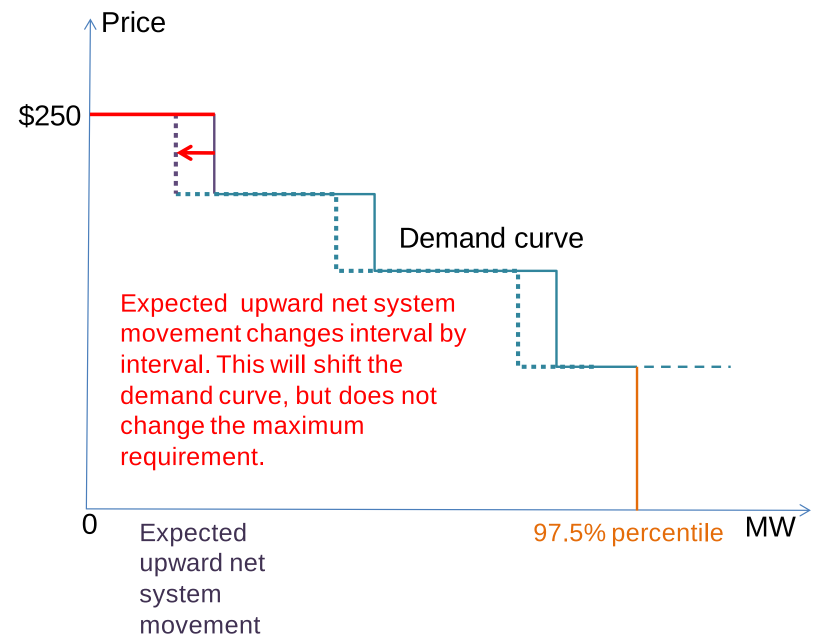

FIGURE 3: UPWARD FLEXIBLE RAMPING REQUIREMENT CURVE WITH UPWARD EXPECTED NET SYSTEM MOVEMENT)

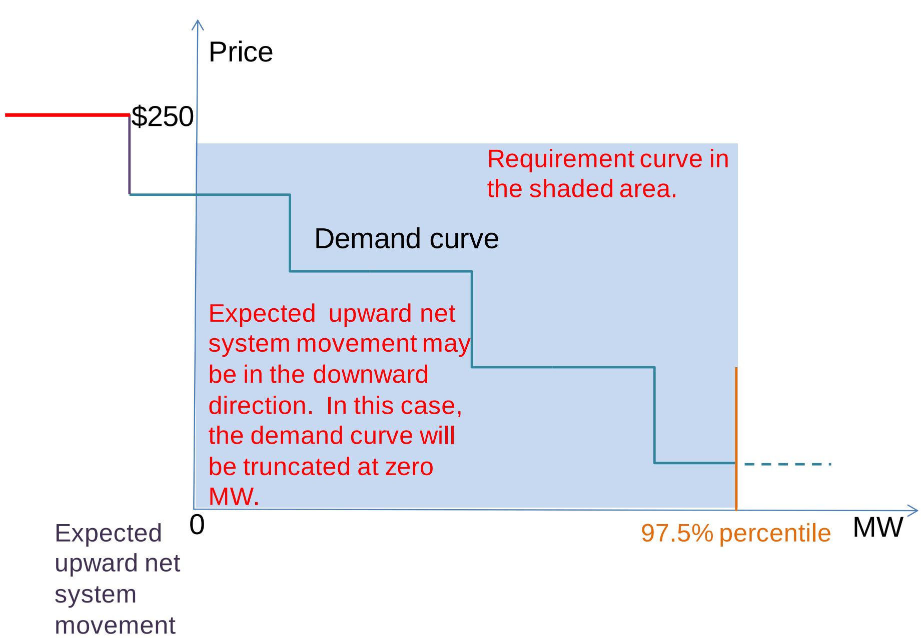

FIGURE 4: UPWARD FLEXIBLE RAMPING REQUIREMENT CURVE WITH DOWNWARD EXPECTED NET SYSTEM MOVEMENT

The minimum requirement can be viewed as related to reliability, because this portion is to meet the projected net system demand, and any reduction of ramping capability would trigger power balance violation in the advisory interval. The flexible ramping demand curve above the minimum requirement can be viewed as related to economic benefit of the product. If the flexible ramping supply is economic, then it is economically efficient to buy more flexible ramping; otherwise, it is better to take some risk of price volatility and buy a lesser amount. Note that the demand curve does not only drive the procurement amount, but also help the optimization determine whether to keep the ramping capability for the future or use it now. For example, when we run the RTD for binding interval t, the flexible ramping awards reserved in interval t-5 is available to the optimization. These awards can either be held in interval t to meet interval t flexible ramping requirement, or a lesser amount held which is released for dispatch in interval t. If the energy supply is tight in interval t, the tight energy supply will compete for flexible ramping capacity, and cause the flexible ramping price to increase. The ramping capability, which has a higher cost than the flexible ramping demand price will be dispatched for energy in interval t. The demand curve strikes the balance between the overall system cost of saving the capacity as flexible ramping or dispatching the capacity as energy.

4.5 MODELING FLEXIBLE RAMPING IN LOOK-AHEAD OPTIMIZATION

The ISO employs a look-ahead optimization in real-time markets. In RTUC, the look-ahead optimization evaluates commitment decisions over a study horizon up to 4.5 hours. In RTD, the look-ahead optimization helps to position the resources in order to meet future load. This feature partially achieves what flexible ramping can do in driving the dispatch. However, the prices resulting from the multi-interval optimization may be more volatile and less efficient than modeling flexible ramping as will be demonstrated in section 4.

With flexible ramping being modeled in real-time markets, the flexible ramping product and requirement will be modeled in all study intervals in the optimization, and not limited to the first interval. How to achieve this is illustrated in Figure 5. Figure 5 naturally extends the real ramp need concept from the first interval to other study intervals in the optimization:

- Upward at t : max{ [upper limit at t+5] – [RTD net system demand at t], 0 }
- Downward at t: max{ [RTD net system demand at t] – [lower limit at t+5], 0 }
- Upward at t+5 : max{ [upper limit at t+10] – [RTD net system demand at t+5], 0 }
- Downward at t+5: max{ [RTD net system demand at t+5] – [lower limit at t+10], 0 }

and so on.

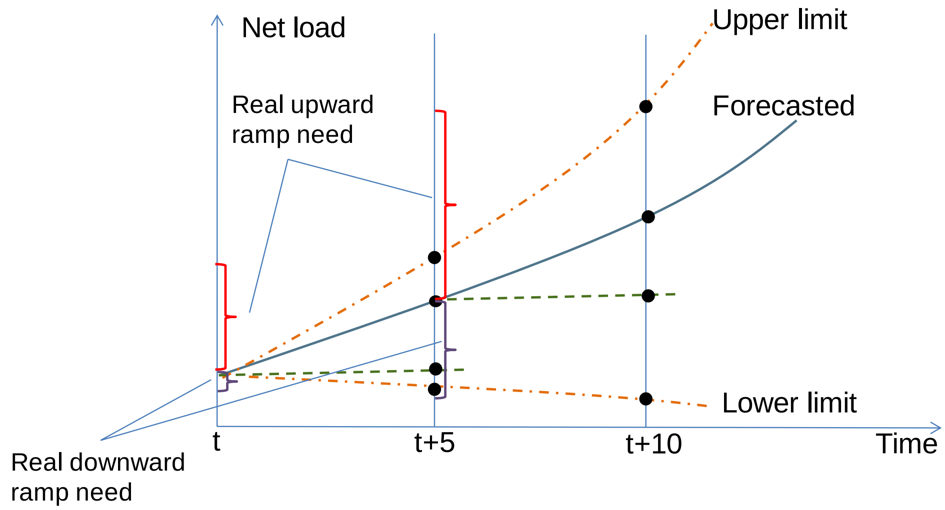

FIGURE 5: REAL RAMP NEED IN LOOK-AHEAD OPTIMIZATION

Flexible ramping capability evaluated at the dispatch level at each interval will be used to meet the requirement for the same interval. The minimum requirement and demand curve can also be extended to the advisory intervals similarly.

Exactly like energy dispatch, only the flexible ramping award in the first RTD interval is financially binding.

4.6 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

This section will summarize the flexible ramping product settlement and discuss the no-pay rules.

4.6.1 FLEXIBLE RAMPING AWARD SETTLEMENT

Similar to energy, the flexible ramping products will be settled through a three settlement system. Day-ahead flexible ramping awards will be settled at the day-ahead flexible ramping product price. The difference between the day-ahead award and the fifteen-minute market award will be settled at the fifteen-minute market flexible ramping product price. The difference between the RTD flexible ramping award and the fifteen-minute market flexible ramping award will be paid the RTD flexible ramping product price.

A resource with day-ahead flexible ramping product award may be scheduled for energy in the fifteen-minute market. In this case, the resource needs to pay back the unavailable flexible ramping capacity at the fifteen-minute market price. In addition, allowing economic buyback in the fifteen-minute market can resolve a double payment issue that may arise due to the granularity difference between day-ahead market and fifteen-minute market. In the day-ahead market, the flexible ramping award is based on the ramping capability from an hourly flat energy schedule. However, if the flexible ramping capability is deployed in the fifteen-minute market in the hour, and the resource cannot hold the day-ahead awarded amount, the resource still keeps the full day-ahead payment if we do not allow the resource to buyback the unavailable capability in real-time. This is a double payment to the resource because the same capacity has been paid both for energy (in the fifteen-minute market) and ramping capability (in day-ahead). Allowing economic buyback will resolve this issue to have the resource pay back for the unavailable flexible ramping capability in fifteen-minute market at the fifteen-minute market price.

A resource with fifteen-minute market flexible ramping product award may be dispatched for energy in RTD. In this case, the resource needs to pay back the unavailable flexible ramping capacity at the RTD price. In addition, allowing economic buyback in RTD can resolve double payment issue that may arise due to the granularity difference between fifteen-minute market and RTD. In the fifteen-minute market, the flexible ramping award is based on the ramping capability between energy schedules with fifteen-minute granularity. However, if the flexible ramping capability is deployed in RTD in the fifteen-minute market, and the resource cannot hold the fifteen-minute market awarded amount, the resource still keeps the full fifteen-minute payment if we do not allow the resource to buyback the unavailable capability in RTD. This is a double payment to the resource because the same capacity has been paid both for energy (in RTD) and ramping capability (in the fifteen-minute market). Allowing economic buyback will resolve this issue to have the resource pay back for the unavailable flexible ramping capability in RTD at the RTD price

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

- Day-ahead procured flexible ramping products will be settled at the day-ahead flexible ramping prices.
- The difference between the FMM flexible ramping award and the day-ahead flexible ramping award will be settled at the FMM flexible ramping price.
- The difference between the RTD flexible ramping award and the FMM flexible ramping award will be settled at the RTD flexible ramping price.
- Flexible ramping products will be included in bid cost recovery. The flexing ramping product bid cost will be added to the total bid cost, and the flexing ramping product payment will be added to total revenue.

4.6.2 SETTLEMENT OF ENERGY FROM RE-DISPATCH TO SUPPORT FRP AWARD

In the Department of Market Monitoring comments on the straw proposal, the DMM sought clarification on the settlement of real-time imbalance energy as a result of FRP awards. The concern regards the classification of energy associated with a re-dispatch necessary to provide the flexible ramping product. For example, a resource may receive an energy dispatch up in order to provide flexible ramping down. The classification of this energy between residual imbalance energy and optimal energy can result in different settlement LMPs. Residual imbalance energy is settled at bid and optimal energy is settled at the LMP. The ISO will treat any ramping energy associated with providing a flexible ramping product as optimal energy. The energy dispatch will be settled at the LMP and the flexible ramping award will be settled at the marginal opportunity cost inclusive of out-of-merit energy dispatches. This appropriately compensates the resource for both the energy dispatch and any opportunity cost of the out-of-merit dispatch necessary to provide a flexible ramping product.

4.6.3 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 the 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 6. 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.

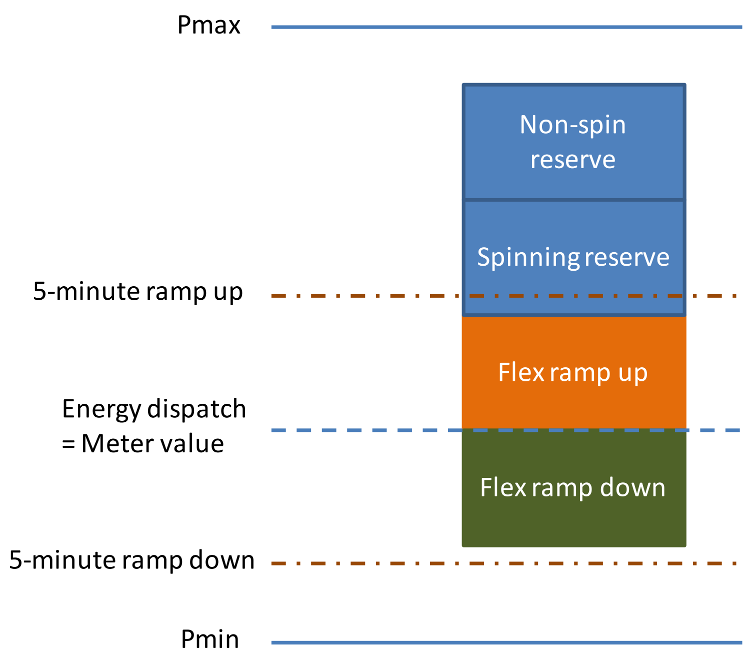

FIGURE 6: A RESOURCE WITH NO FLEXIBLE CAPCITY PAYMENT RECISSIONS

- **Undispatchable Capability**: There are two subcategories of Undispatchable Capability:

  Availability-Limited Capability: If a resource's capability is re-rated in the real-time market , the total amount of flexible ramping Awards may not be available in RTD for dispatch due to the availability limitation. This is illustrated in Figure 7, 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.

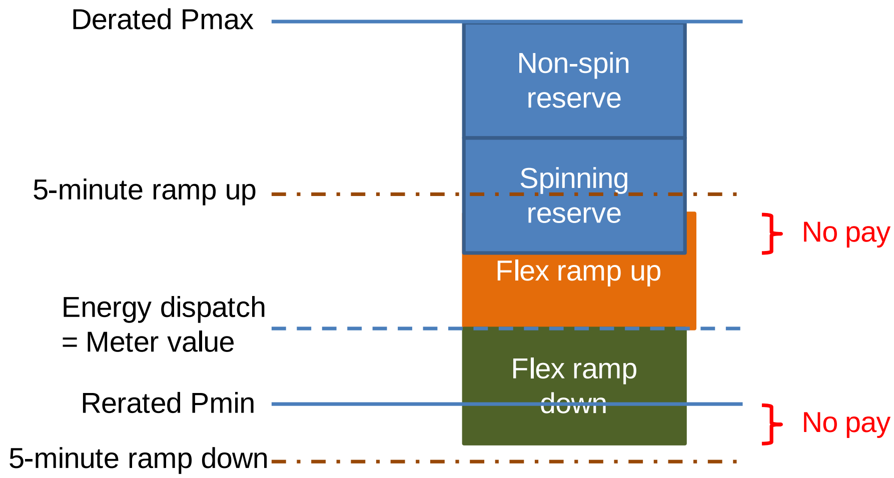

FIGURE 7: A RESOURCE WITH UNAVAILABLE FLEXIBLE RAMPING CAPABILITY NO PAY

Ramp-Limited Capability: Flexible ramping products are required to be delivered in 5 minutes. If a resource does not have the 5-minute Ramp Rate capability in RTD 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 8.

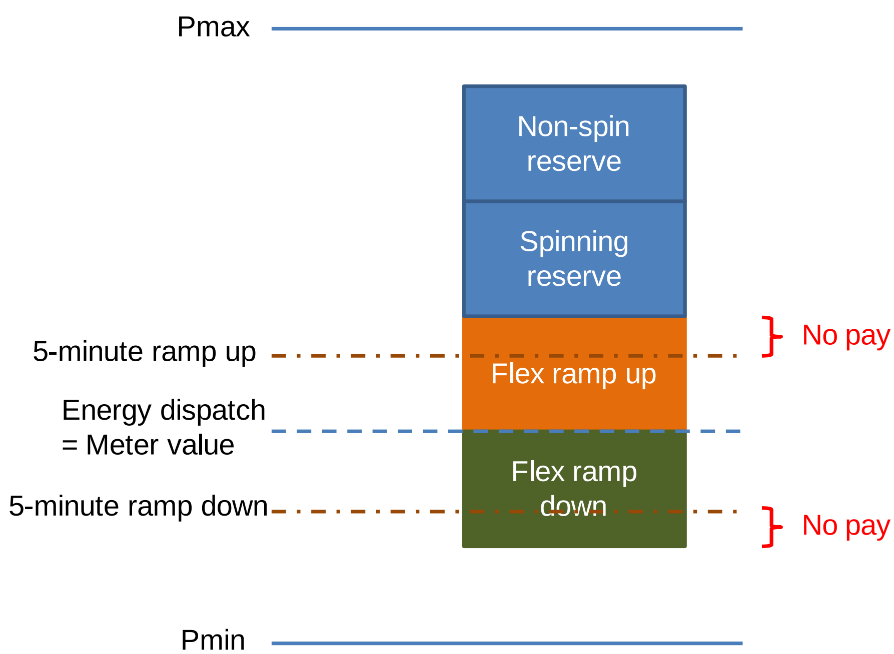

FIGURE 8: A RESOURCE WITH RAMP-LIMITED NO PAY

- **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. If the dispatch is in the same direction as the flexible ramping award, then it is considered a flexible ramping deployment. Uninstructed deviations in the opposite direction of the instructions are considered undelivered capability, and are subject to no-pay charge at the real-time flexible ramping price. Uninstructed deviations in the same direction of the instructions are not subject to undelivered capability charge. These are illustrated in Figure 9.

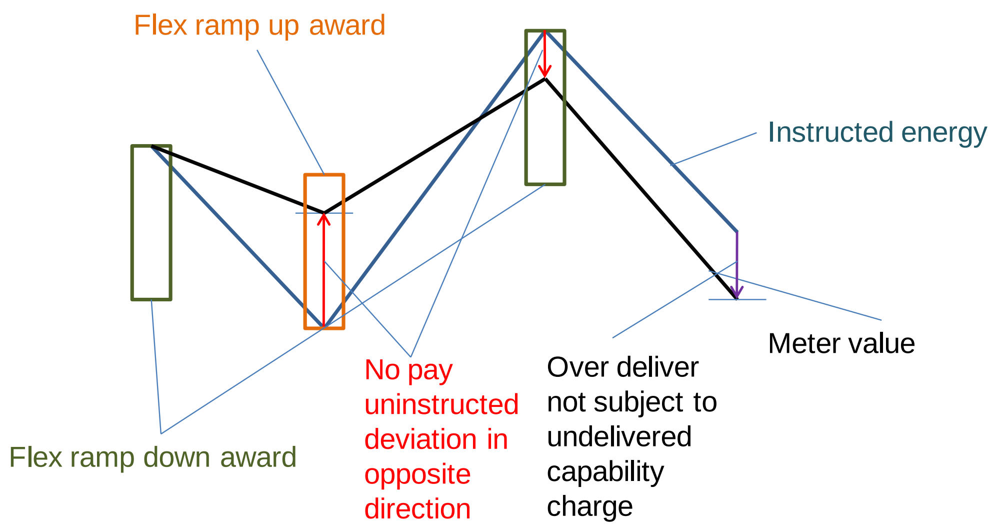

FIGURE 9: UNDELIVERED CAPABILITY NO PAY

- **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 RTD may cause flexible ramping capability to be unavailable to the ISO.

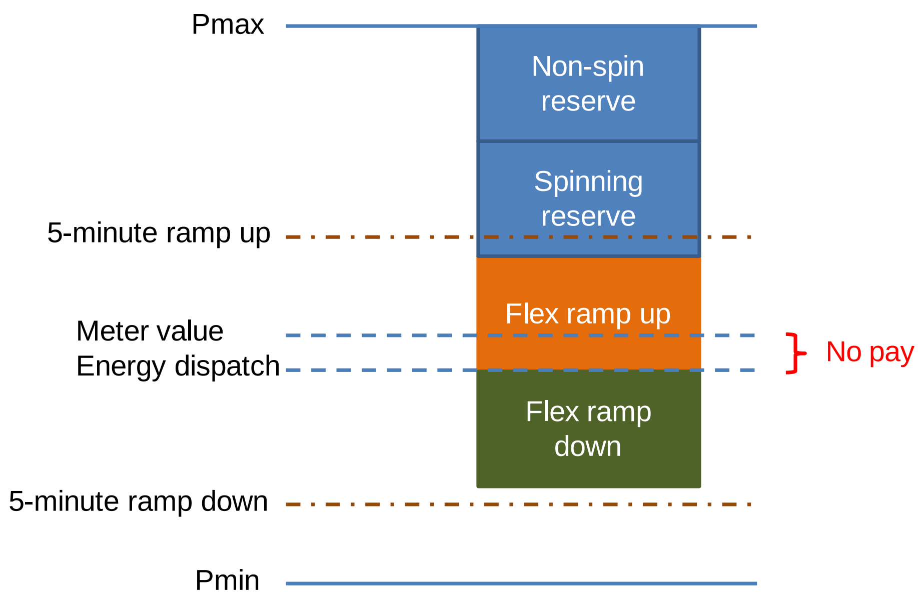

FIGURE 10: A RESOURCE WITH UNAVAILABLE CAPABILITY NO PAY

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

5. FLEXIBLE RAMPING EXAMPLES

In this section, we will discuss several examples. The examples in Section 4.1 will demonstrate the properties of the flexible ramping product in RTD market. The example in Section 4.2 will demonstrate how the flexible ramping product is settled.

5.1 PROPERTIES OF FLEXIBLE RAMPING

In this section, we use an RTD example to demonstrate the properties and benefits of flexible ramping under the assumption that net system movement is accurately predicted. For simplicity, we only consider the interaction between energy and the flexible ramping product, and ignore ancillary services.

5.1.1 UPWARD FLEXIBLE RAMPING

Assume there are two 500 MW online resources in the system that could provide flexible ramping up. The bids and parameters of the two generators are listed in Table 6. G1 has 100 MW/minute ramp rate, and G2 has 10 MW/minute ramp rate. G1 is more economic in energy than G2. They both have zero cost bids for providing flexible ramping.

Gen	EN Bid	FRU bid	FRD bid	En init	Ramp rate	Pmin	Pmax
G1	25	0	0	400	100	0	500
G2	30	0	0	0	10	0	500

EN – energy FRU – flexible ramping up FRD – flexible ramping down

TABLE 3: RESOURCE BIDS, INITIAL CONDITION AND OPERATIONAL PARAMETERS

We will consider four scenarios:

- scenario 1: single interval RTD optimization without upward flexible ramping.
  - [Load at t] = 420 MW
- scenario 2: single interval RTD optimization with upward flexible ramping.
  - [Load at t] = 420 MW
  - [Upward flexible ramping requirement at t] = 170 MW
  - [Downward flexible ramping requirement at t] = 0 MW
- scenario 3: two-interval RTD optimization without upward flexible ramping

- [Load at t] = 420 MW
- [Load at t+5] = 590 MW

- scenario 4: two-interval RTD optimization with upward flexible ramping
  - [Load at t] = 420 MW
  - [Load at t+5] = 590 MW
  - [Upward flexible ramping requirement at t] = 170.01 MW
  - [Downward flexible ramping requirement at t] = 0 MW

The solution for scenario 1 is listed in Table 7. In scenario 1, load is met by the most economic resource G1, and G1 sets the LMP at $25.

	Interval t (LMP=$25)		
gen	Energy	Flex-ramp up	Flex-ramp down
G1	420		
G2	0		

TABLE 4: SINGLE-INTERVAL RTD DISPATCH WITHOUT UPWARD FLEXIBLE RAMPING

The solution for scenario 2 is listed in Table 8. In scenario 2, in order to meet 170 MW upward flexible ramping, G1 needs to be dispatched down in order to make room for upward flexible ramping. As a result, G1 do not have extra capacity to meet extra load, and LMP is set by G2 at $30. Note the upward flexible ramping requirement causes the LMP to increase compared with scenario 1. The upward flexible ramping price FRUP is set by G1's energy opportunity cost $30 – $25= $5.

	Interval t (LMP=$30, FRUP=$5)		
gen	Energy	Flex-ramp up	Flex-ramp down
G1	380	120	
G2	40	50	

TABLE 5: SINGLE-INTERVAL RTD DISPATCH WITH UPWARD FLEXIBLE RAMPING

The solution for scenario 3 is listed in Table 9. In scenario 3, there is not flexible ramping requirement. However, the look-ahead optimization projects a 170 MW of upward load ramp from interval t to t+5, which equals the upward flexible ramping requirement in scenario 2. Interestingly, the look-ahead optimization produces the same dispatch for interval t as in scenario 2, but different LMPs. The dispatch is the same because the look-ahead load ramp also requires the same amount of ramping capability as the flexible ramping requirement in interval t. The LMPs are different because there is an interaction between the energy price and flexible ramping price. Let's denote the LMP in scenario 2 interval t as LMP^{S2}, and the LMP in scenario 2 interval t as LMP^{S3}. The physical meaning of LMP^{S2} is the system total cost to meet one extra MW of load in interval t, while maintaining the same 170 MW of upward ramping capability. The physical meaning of LMP^{S3} is the system total cost to meet one extra MW of load in interval t, and reducing the upward ramping capability in interval t to 169 MW. Therefore, in this case, $LMP^{S3} = LMP^{S2} - FRUP^{S2} = 30 - 5 = \$25$. From the LMP structural differences, we can see that the LMP form the look-ahead optimization is actually not a pure energy price, but rather a price consists of energy price and flexible ramping prices. When net system demand is increasing, which creates more upward ramp need, the look-ahead optimization may suppress the energy price in the first interval.

This effect may make resources be dispatched inconsistently with their offers in the look-ahead optimization with only the first interval being settled. For example, G2 is dispatched for 40 MW with bid cost $30/MWh, but will only be paid the LMP $25/MWh. This implies the ISO has to make bid cost recovery for resource G2. Some people may think that if the predicted load ramp materializes in interval t+5, the LMP for t+5 will be $35/MWh, and makes G2 revenue adequate to cover its bid cost. However, this perception is incorrect. To demonstrate this, assume all resources exactly follow instructions, and the load forecast for interval t+10 is 620 MW. To produce uniquely determined LMP, we will consider two cases: load forecast for interval 5 is slightly lower than 590 MW, and load forecast for interval t+5 is slightly higher than 590 MW. If the load forecast for interval t+5 goes slightly lower than 590 MW, say 589.99 MW, the LMP for interval t+5 will be $30/MWh instead of $35/MWh. This means G2 is still short in revenue. If the load forecast for interval t+5 goes slightly higher than 590 MW, say 590.01 MW, the LMP for interval t+5 will be $1000/MWh due to power balance violation of 0.001 MW. Neither case produces desired results. If the load forecast for interval t+5 is exactly 590 MW, the LMP will be between $30/MWh and $1000/MWh depending on the optimization solver. This rarely happens in reality, because there is always some load or generation deviation to make net system demand higher or lower than expected.

	Interval t (LMP=$25)			Interval t+5 (LMP=$35)		
gen	Energy	Flex-ramp up	Flex-ramp down	Energy	Flex-ramp up	Flex-ramp down
G1	380			500		
G2	40			90		

TABLE 6: LOOK-AHEAD RTD DISPATCH WITHOUT UPWARD FLEXIBLE RAMPING

In scenario 4, both flexible ramping and look-ahead are modeled in the optimization. In order to have uniquely determined prices, we set upward flexible ramping requirement slightly higher than expected load ramp 170 MW. The results are listed in Table 10, which converge to scenario 2 in the first interval. If the flexible ramping requirement is slightly lower than the expected load ramp, the solution would converge to scenario 3.

	Interval t (LMP=$30, FRUP=$5)			Interval t+5 (LMP=$30)		
gen	Energy	Flex-ramp up	Flex-ramp down	Energy	Flex-ramp up	Flex-ramp down
G1	379.99	120.01		500		
G2	40.01	50		90		

TABLE 7: LOOK-AHEAD RTD DISPATCH WITH FLEXIBLE RAMPING UP REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED UPWARD LOAD RAMP

Interval t+5	Load = 589.99 MW	Load = 590.01 MW
G1	500	500
G2	89.99	90
LMP	$30/MWh	$1000/MWh

TABLE 8: POSSIBLE LOOK-AHEAD RTD DISPATCH WITHOUT FLEXIBLE RAMPING IN INTERVAL T+5

5.1.2 DOWNWARD FLEXIBLE RAMPING

Again, assume two 500 MW resources are online in the system that can provide flexible ramping. The bids and parameters of the two generators are listed in Table 12. G1 has 10 MW/minute ramp rate, and G2 has 100 MW/minute ramp rate. G1 is more economic in energy than G2. They both have zero cost for providing flexible ramping.

Gen	EN Bid	FRU bid	FRD bid	En init	Ramp rate	Pmin	Pmax
G1	25	0	0	300	10	0	500
G2	30	0	0	100	100	0	500

EN – energy FRU – flexible ramping up FRD – flexible ramping down

TABLE 9: RESOURCE BIDS, INITIAL CONDITION AND OPERATIONAL PARAMETERS

We will consider four scenarios:

- scenario 1: single interval RTD optimization without downward flexible ramping.
  - [Load at t] = 380 MW
- scenario 2: single interval RTD optimization with downward flexible ramping.
  - [Load at t] = 380 MW
  - [Upward flexible ramping requirement at t] = 0 MW

- [Downward flexible ramping requirement at t] = 170 MW

- scenario 3: two-interval RTD optimization without downward flexible ramping
  - [Load at t] = 380 MW
  - [Load at t+5] = 210 MW
- scenario 4: two-interval RTD optimization with downward flexible ramping
  - [Load at t] = 380 MW
  - [Load at t+5] = 210 MW
  - [Upward flexible ramping requirement at t] = 0 MW
  - [Downward flexible ramping requirement at t] = 170.01 MW

The solution for scenario 1 is listed in Table 13. In scenario 1, load is met by both G1 and G2, and G2 sets the LMP at $30. Although G1 is more economic than G2, its output 350 MW has been limited by its ramp rate 10 MW/minute from its initial condition 300 MW, so it cannot set the LMP.

	Interval t (LMP=$30)		
gen	Energy	Flex-ramp up	Flex-ramp down
G1	350		
G2	30		

TABLE 10: SINGLE-INTERVAL RTD DISPATCH WITHOUT DOWNWARD FLEXIBLE RAMPING

The solution for scenario 2 is listed in Table 14. In scenario 2, in order to meet 170 MW downward flexible ramping, G2 needs to be dispatched up in order to provide downward flexible ramping. As a result, G1's output will be reduced in order to maintain the power balance, and G1 sets the LMP at $25. Note the downward flexible ramping requirement causes the LMP to decrease compared with scenario 1. The downward flexible ramping price FRDP is set by G2's energy price deficit $30 – $25= $5. The FRDP price is to compensate G2 such that G2's revenue including both energy and flexible ramping down can cover its energy bid cost $30. As a result, there is no revenue shortage for G2, and no need for bid cost recovery.

	Interval t (LMP=$25, FRDP=$5)		
gen	Energy	Flex-ramp up	Flex-ramp down
G1	260		50
G2	120		120

TABLE 11: SINGLE-INTERVAL RTD DISPATCH WITH DOWNWARD FLEXIBLE RAMPING

The solution for scenario 3 is listed in Table 15. In scenario 3, there is no flexible ramping down requirement. However, the look-ahead optimization projects a 170 MW of downward load ramp from interval t to t+5, which equals the downward flexible ramping requirement in scenario 2. Interestingly, the look-ahead optimization produces the same dispatch for interval t as in scenario 2, but different LMPs. The dispatch is the same because the look-ahead load ramp also requires the same amount of ramping capability as the flexible ramping requirement in interval t. The LMPs are different because there is an interaction between the energy price and flexible ramping price. Let's denote the LMP in scenario 2 interval t as LMP^{S2}, and the LMP in scenario 2 interval t as LMP^{S3}. The physical meaning of LMP^{S2} is the system total cost to meet one extra MW of load in interval t, while maintaining the same 170 MW of downward ramping capability. The physical meaning of LMP^{S3} is the system total cost to meet one extra MW of load in interval t, and increasing the downward ramping capability in interval t to 171 MW. Therefore, in this case, $LMP^{S3} = LMP^{S2} + FRDP^{S2} = 25 + 5 = \$30$. From the LMP structural differences, we can see that the LMP form the look-ahead optimization is actually not a pure energy price, but rather a price consists of energy price and flexible ramping prices. When net system demand is increasing, which creates more downward ramp need, the look-ahead optimization will increase the energy price in the binding interval.

This effect may make resources be dispatched inconsistently with their offers in the look-ahead optimization with only the first interval being settled. For example, G1 is dispatched at 260 MW, but with the LMP being $30/MWh, it should be dispatched at a higher level. Some people may think that if the predicted load ramp materializes in interval t+5, the LMP for t+5 will be $20/MWh, and makes G2's LMP consistent with its bid over these two intervals. However, this perception is incorrect because the $20 LMP is not final settlement price. To see this, assume all resources exactly follow instructions, and the load forecast for interval t+10 is 190 MW. To produce uniquely determined LMP, we will consider two cases: load forecast for interval 5 is slightly lower than 380 MW, and load forecast for interval t+5 is slightly higher than 380 MW. If the load forecast for interval t+5 goes slightly lower than 380 MW, say 379.99 MW, the LMP for interval t+5 will be –$35/MWh set by power balance violation penalty. If the load forecast for interval t+5 goes slightly higher than 380 MW, say 380.01 MW, the LMP for interval t+5 will be $25/MWh set by G1 instead of the projected $20, so G1 will be over paid $5 for interval t+5. Neither case produces desired results. If the load forecast for interval t+5 is exactly 380 MW, the LMP will be between –$35/MWh and $20/MWh depending on the optimization solver. This rarely happens in reality, because there is always some load or generation deviation to make net system demand higher or lower than expected.

	Interval t (LMP=$30)			Interval t+5 (LMP=$20)		
gen	Energy	Flex-ramp up	Flex-ramp down	Energy	Flex-ramp up	Flex-ramp down
G1	260			210		
G2	120			0		

TABLE 12: LOOK-AHEAD RTD DISPATCH WITHOUT DOWNWARD FLEXIBLE RAMPING

	Interval t (LMP=$25, FRDP=$5)			Interval t+5 (LMP=$25)		
gen	Energy	Flex-ramp up	Flex-ramp down	Energy	Flex-ramp up	Flex-ramp down
G1	259.99		50	210		
G2	120.01		120.01	0		

TABLE 13: LOOK-AHEAD RTD DISPATCH WITH FLEXIBLE RAMPING DOWN REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED DOWNWARD LOAD RAMP

Through these examples, we observed that:

- Look-ahead optimization may produce composed energy price, which consists of pure energy price, and ramp prices. The composed energy price may not be consistent with the resource's energy offer price if only the binding interval is settled, and may trigger bid cost recovery. The composed energy price is also very sensitive to deviations from the expected net system demand level because there is no dispatch margin built in the optimization. The composed energy price can be very volatile.
- Flexible ramping can decompose the pure energy price and flexible ramping prices, and provide more transparent and less volatile price signals. These prices are also more consistent with the energy offers, and reduce the need for bid cost recovery. These are advantages of flexible ramping even if net system demand could be predicted with high accuracy.

5.2 SETTLMENT EXAMPLE

Now let's see how flexible ramping is settled day-ahead and real-time markets. Assume a generator G1 gets awards in both day-ahead and RTD. We have omitted the optimization details of how the resource is awarded in order to focus on the settlement. Let's look at the energy settlement first.

G1	Schedule (MW)		Price ($/MWh)		IIE/UIE (MWh)		Settlement ($)		
Time	7:00	7:05	7:00	7:05	7:00	7:05	7:00	7:05	Total
IFM	450	450	25.83	25.83			968.63	968.63	1937.25
FMM	402	402	30	30	–48/12	–48/12	–120	–120	–240
RTD	302	500	25	36	–100/12	98/12	–208.33	294	85.67
Meter	420	420	25	36	118/12	–80/12	245.83	–240	5.83
Total									1788.75

TABLE 14: AN ENERGY SETTLEMENT EXAMPLE

The Instructed Imbalance Energy (IIE) is FMM energy – IFM energy and RTD energy – FMM energy. The Uninstructed Imbalance Energy (UIE) is metered energy – RTD energy.

Flexible ramping is settled in a way very similar to energy. Similar to IIE and UIE, the delta FRU is

FMM FRU – IFM FRU and RTD FRU – FMM FRU, and the unavailable FRU is available FRU based on meter – RTD FRU.

G1	Schedule (MW)		Price ($/MWh)		Delta/unavailable FRU (MWh)		Settlement ($)		
Time	7:00	7:05	7:00	7:05	7:00	7:05	7:00	7:05	Total
IFM	20	20	5	5			8.33	8.33	16.67
FMM	15	15	6	6	−5/12	−5/12	−2.5	−2.5	−5
RTD	6	9	0	10	−9/12	−6/12	0	−5	−5
Meter	7	7	0	10	1/12	−2/12	0	−1.67	−1.67
Total									5

TABLE 15: A FLEXIBLE RAMPING SETTLEMENT EXAMPLE

6. OTHER DESIGN ELEMENTS

6.1 GRID MANAGEMENT CHARGES

The flexible ramping product will be subject to the bid segment fee in the day-ahead market and the market services fee based upon gross awarded MW of flexible ramping products similar to energy settlement across the IFM, FMM and RTD.

6.2 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.

7. COST ALLOCATION

The ISO has applied the cost allocation guiding principles in developing the cost allocation proposal for the flexible ramping product. The ISO briefed the Board of Governors on the guiding principles at the May 2012 board meeting. The cost allocation guiding principles have seven elements: (1) Causation, (2) Comparable Treatment, (3) Efficient Policy Achievement, (4) Incentivize Behavior, (5) Manageable, (6) Synchronized, and (7) Rational.

7.1 PROPOSED MOVEMENT BASELINE FOR FLEXIBLE RAMPING PRODUCT

The ISO proposes to initially allocate the costs for the flexible ramping product based upon movement that requires changes in real-time dispatch of resources. With the introduction of the FERC Order No. 764 market design changes, the ISO modified the settlement interval from ten minutes to five minutes. Movement for load is defined as changes in observed load every five minutes. Movement for supply is defined as the combined changes in uninstructed imbalance energy and change in internal self-schedules every five minutes. Movement for fixed ramps is calculated based upon the change in MWhs deemed delivered every five minutes for hourly static imports and exports. There is no netting of five minute intervals within the hour, thus a category can be allocated both flexible ramping up and flexible ramping down in a given hour. In the event, that there is movement only in one direction by all three categories in all five minute intervals for an hour, the flexible ramping costs of the product with no movement for the hour will initially be allocated to the Load category and then reversed during the monthly resettlement. The ISO believes that movement is better aligned with the procurement decisions of the flexible ramping product because the movement represents the changes in RTD dispatch necessary to manage the system.

The expectation of potential movement across all market participants results in the procurement of the flexible ramping product. When flexible ramping products are procured, the total system movement that may be realized in RTD is the driver of the procurement target. There may be instances where two market participants offset each other's movement which decreases the overall system requirement. For example, assume self-schedule generation is increasing 75MW and Load is increasing 100MW and ignore deviations, the total system movement is 25MW and requires 25MW of the flexible ramping up product. This offsetting impact decreases the quantity of the flexible ramping product the ISO must procure and is reflected in a lower overall procurement target and a lower relative initial allocation to each of the categories. While the allocation approach within a given category may be different, such as the deviation threshold in the supply bucket, the category specific allocation does not impact the initial allocation to the category. In addition, once the category specific allocation is completed, the costs for that category must be fully absorbed by market participants in the specific category.

The flexible ramping cost is the product of the procurement target and the respective market clearing price paid to suppliers of the flexible ramping product. The costs to be allocated include capacity procured in day-ahead market, fifteen-minute market and real-time dispatch. The costs are aggregated to a BAA level if there are regional requirement within a BAA or shared constraints of BAAs participating in the EIM. The flexible ramping product costs are represented by the blue (Up) and green (Down) pies in Figure 13.

The upward flexible ramping product is procured to address negative movement between dispatch intervals. The downward flexible ramping product is procured to address positive movement between dispatch intervals.

All resources in a given category will be netted prior determining the initial division of system wide costs. By netting across all supply resources and scheduling coordinators with fixed ramps, the movement will be comparable with the load category which nets deviations across all load serving entities. The ISO will then determine an appropriate billing determinant for each category to allocate the costs to individual resources.

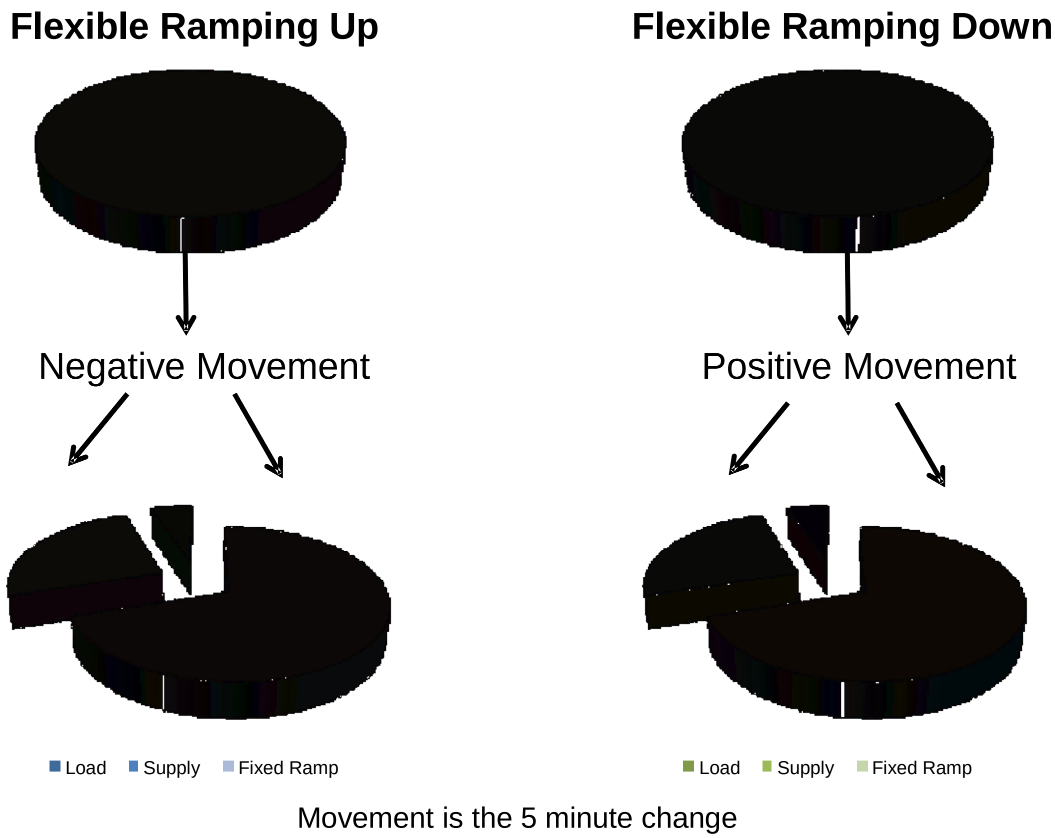

FIGURE 11 - FLEXIBLE RAMPING PRODUCT COST ALLOCATION

7.2 BILLING DETERMINANT OF LOAD CATEGORY

In the real-time market, Load does not submit economic bids or schedules. The ISO commits resources in RTUC to meet the CAISO forecast of CAISO demand (CFCD) and dispatches resource in RTD to meet the 5-minute load forecast. While metering of Load for energy settlement purposes is done on an hourly basis, the ISO can measure system demand with five minute granularly based upon actual observations. Five minute granularity aligns with the metering of supply resources.

The ISO is not requiring more granular metering of load by load serving entities. The ISO proposes to use gross uninstructed imbalance energy to determine the share of flexible ramping costs attributable to each load serving entity. While uninstructed imbalance energy is based upon day-ahead scheduled load, the ISO believes that if load serving entities more accurately predict hour to hour load ramp in the day-ahead market, the ISO should be able to reduce the amount of flexible ramping procured when the rate of hourly supply ramps are aligned with actual load movement.

If a load serving entity uses five minute metering, such as load following metered sub-systems, then the load serving entity would be considered within the supply category discussed in the next section. The allocation will be based upon five minute net uninstructed imbalance energy. It should be noted that in addition to the flexible ramping product allocation, load following MSS are subject to penalties for excessive deviations.

7.3 BILLING DETERMINANT OF SUPPLY CATEGORY

The supply category will be allocated based upon the five minute uninstructed deviations plus changes in real-time self schedules. Thus for conventional resources, uninstructed deviations will net against self-schedule changes. Under FERC Order No. 764 market design changes, variable energy resources can use the ISO forecast to self-schedule or bid in to the real-time markets. If a variable energy resource elects to self-schedule its forecasted output, then the five-minute self-schedule changes will be netted with uninstructed imbalance energy to allocate the flexible ramping costs. If a variable energy resource submits an economic bid only, then the resource will only be allocated the flexible ramping product for uninstructed imbalance energy.

While delta UIE is used for the initial allocation to the supply category, the ISO agrees with previous stakeholder comments that gross UIE provides greater clarity to incentivize behavior of resources. As a result, supply resources will be allocated based upon their self-schedule movement netted against uninstructed imbalance energy for each 5-minute interval.

At a previous technical workshop, concerns were raised that a resource could change its PMin to effectively self-schedule the resource and avoid the cost allocation to self-schedule changes. Changes to PMin can only be made based upon physical changes in the resource. PMin changes that are not based upon the operational characteristics of the resources are considered capacity withholding by the ISO.

7.3.1 BASELINE TO MEASURE DEVIATIONS FOR CONVENTIONAL RESOURCES

The flexible ramping products are procured for generation which has deviated from ISO dispatch. If a resource deviates from the ISO dispatch, the subsequent RTD interval will dispatch other generation to make up the shortfall. In addition, if a resource self-schedules in real time, the ISO uses penalty prices to honor the ramp even if the movement is counter to current system conditions. This requires the ISO to have other dispatchable resources available to manage this ramp. Therefore the ISO will use the sum of standard ramping energy, ramping energy deviations, residual imbalance energy and uninstructed imbalance energy to calculate the gross allocation quantity.

Imports/Exports that are dynamically transferred are responding to 5 minute RTD dispatches, these resources will also be allocated in within this category.

7.3.2 THRESHOLD FOR ALLOCATION

Several stakeholders have commented that a threshold, similar to the uninstructed deviation penalty (not currently implemented) threshold, should be considered for allocating the supply category. The threshold would not be used for the initial splitting of the flexible ramping costs in to the three categories, but would recognize that perfect adherence to dispatch is not realistic based upon resource operational characteristics. However, if a threshold was implemented the cost allocation should be more manageable and resources would be incentivized to make investments that could improve their performance to dispatch to stay within the threshold.

The ISO proposes to allow a 3% threshold for allocation within the supply category. Unlike the uninstructed deviation penalty (not currently implemented), the threshold will be based upon the resource's instructed energy. For example, assume a resource has instructed energy of 10 MWh in a given settlement interval, if the resource's actual metered output was less than 9.7 MWh, the resource's deviation would be allocated flexible ramping up costs. If the resource's actual metered output was greater than 10.3 MWh, the resource would be allocated flexible ramping down costs. Stated differently, if the change in uninstructed deviations exceeds 3% of the instructed energy, the resource will be allocated a portion of the supply category costs.

The ISO agrees with stakeholder comments that a minimum threshold should also apply. The ISO proposes that threshold should be the minimum of 3% instruction or 5 MWh divided by 12 for a given five minute settlement interval.

The monthly resettlement and the initial netting within the supply category reduce the risk that there would be insufficient deviations to allocate the supply costs.

7.4 BILLING DETERMINANT OF FIXED RAMP CATEGORY

The fixed ramp category allocates cost based upon the net movement within a SC for imports, exports, and operational adjustments. Static hourly schedules for Imports and Exports require the ISO to manage dispatchable resources to honor the ramping for between schedule changes.   Hourly static schedule changes honor a 20 minute ramp.

The ISO must honor the hourly modeled ramps even if the ramp is counter to existing system conditions. By using movement for fixed ramps, when the fixed ramp movement is aligned with the load change, the allocation will be for the flexible ramping product in the opposite direction of load movement. For example, in the morning load pull, the ISO will require more flexible ramping up. If in this hour, net imports are increasing, the fixed ramp movement will be positive which results in an allocation towards flexible ramping down.

The ISO disagrees with stakeholder comments that static intertie ramps which are aligned with Load should receive a credit as this ramp is supporting Load. This argument misconstrues what flexible ramping products are procured to support. The ISO procures sufficient flexible ramping product to meet the total net system movement and does not differentiate between expected ramping and variability/uncertainty. This includes the net movement in load, net movement in supply resources UIE, and net movement in fixed ramps. Assume that load was ramping up 200 MW, fixed ramps were ramping up 50 MW and there was no supply category movement, the procurement target for flexible ramping up would be 150 MW and the flexible ramping down requirement would be zero. In this example, the fixed ramp category would be allocated flexible ramping down which has a zero requirement. Fixed ramps are allocated costs when system conditions require the ISO dispatch to honor the fixed ramp that our counter to system conditions.

7.5 COST ALLOCATION GRANULARITY WITHIN THE 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 hourly level granularity. Previously, the ISO was concerned that this may lead to the need to implement a twotiered allocation due to insufficient deviations. However, the ISO believes that the monthly re-settlement of flexible ramping costs at the resource level is sufficient to mitigate the need for a second tier. As Figure 18 illustrated below the flexible ramping constraint has seen sufficient hourly differences.

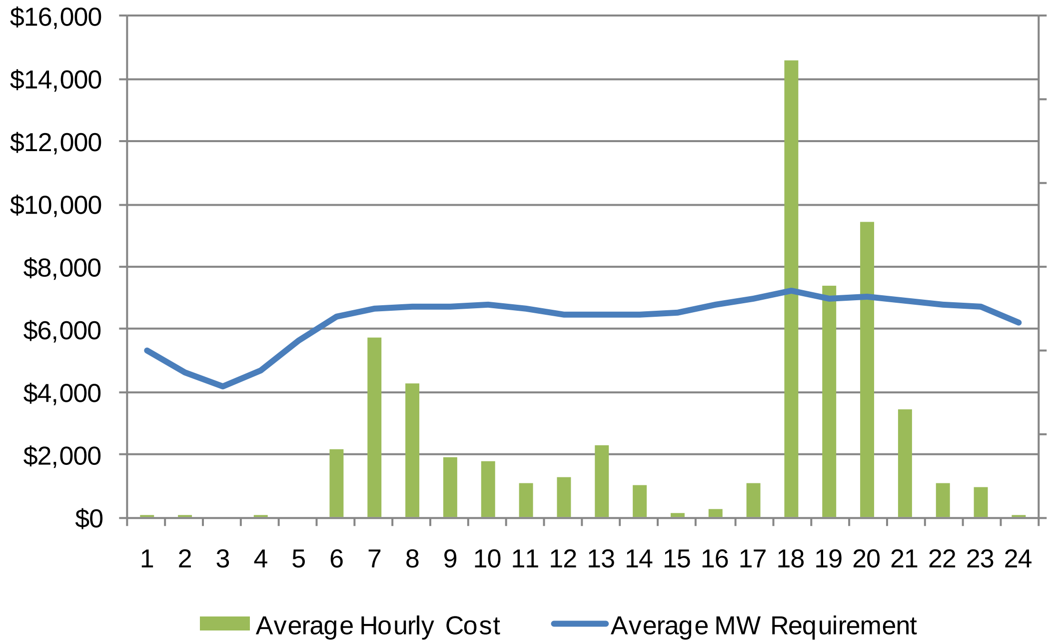

FIGURE 12 - HOURLY FLEXIBLE RAMPING CONSTRAINT COSTS JANUARY TO MARCH 2012

7.6 MONTHLY RE-SETTLEMENT

Since the flexible ramping products are procured based upon forecasted movement, 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 for each operating hour. 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 within a category for each operating hour. On an hourly basis, scheduling coordinators will be allocated flexible ramping product costs as a share of their deviations. At the end of the month, these hourly charges will be reversed, and the scheduling coordinator will be charge the monthly rate for each of its five minute deviations for each hour of the day.

The monthly re-settlement process is done separately for both the flexible ramping up and flexible ramping down products.

> Step 1 – Determine hourly balancing authority area cost for the product. This is calculated by summing the costs of all constraints across all markets. This includes the BAA level constraint, any regional constraints within the balancing authority, and the balancing authority area's share of combined constraints in the EIM (See section 8.2).

Step 2 – Determine the 5-minute gross movement for each category in the hour within the balancing authority area. There is no netting of movement across 5-minute intervals.

Step 3 – Calculate costs of each category using its share of 5-minute movement for the relevant product.

Step 4 – Allocate the hourly costs within the category according to the rules of that category using 5-minute data from that hour. This initial allocation ensures the ISO is revenue neutral for the day.

Step 5 – At the end of the month, reverse all hourly settlements within the balancing authority area.

Step 6 – Sum product costs for each hour over the month.

Step 7 – Sum the 5-minute gross movement for each category for each hour over the month.

Step 8 – Calculate the monthly cost for each hour by using the category's share of the monthly 5-minute movement of the relevant product.

Step 9 – Allocate the monthly costs within the category according to the rules of the category using 5-minute data summed for that hour over the month.

8. ENERGY IMBALANCE MARKET

With the introduction of the flexible ramping products, the ISO will introduce a downward ramping sufficiency evaluation to address real-time leaning due to over-supply. In addition, the cost allocation discussed in section 6 will be extended to all resources in an EIM Entity BA, including EIM Participating Resources. For purposes of cost allocation, base schedules of non-participating resources will be considered self-schedules in the supply category. Thus the EIM Entity Scheduling Coordinator will be allocated flexible ramping costs for changes in base schedules from non-participating resources because the ramps between hourly base schedules must be honored by RTD.

The EIM Administrative Fee does not apply to flexible ramping product awards. Since there is no bidding allowed in the real-time market, the bid segment fee also does not apply.

8.1 DOWNWARD RESOURCE SUFFICIENCY EVALUATION

The Market Operator will calculate the flexible ramping down requirement for each BAA individually and for the EIM footprint, which recognizes the diversity benefits of the EIM. The diversity benefit will then be allocated pro rata to individual EIM Entity BAAs for use in the flexible ramping down sufficiency test. The total system requirement will not exceed the sum of the individual BAA flexible ramping requirements, since in this case the requirement can be met with no transfers between BAAs.

If an EIM Entity BAA has a net incoming EIM transfer (net imbalance energy import with reference to the base net schedule interchange) before the operating hour, then it has partially fulfilled its flexible ramping down requirement for that hour because it can retract that EIM transfer during the hour as needed. In this case, the Market Operator will apply a flexible ramping down requirement credit in the flexible ramping down sufficiency test for that EIM Entity BAA equal to the net incoming EIM transfer before the operating hour. There will be no such credit for an EIM Entity BAA that has a net outgoing EIM transfer (net imbalance energy export with reference to the base net schedule interchange) before the operating hour; the flexible ramping down requirement for that EIM Entity BAA in the flexible ramping down sufficiency test will not be affected by the net outgoing EIM transfer. That EIM Entity BAA will be considered sufficient if it meets its own flexible ramping down requirement, with any applicable EIM diversity benefit, irrespective of the outgoing EIM transfer, which is the result of optimal dispatch in the EIM.

The individual EIM Entity BAA requirement for the flexible ramping down sufficiency test will be calculated as follows:

$$FRR'_i = \max\left(\max(0, FRR_i - NEC_i), FRR_i \frac{TFRR - DB}{TFRR} - NI_i\right)$$

Where:

FRR'_i is the flexible ramping down requirement for EIM Entity *i* with diversity benefit;

FRR_i is the flexible ramping down requirement for EIM Entity *i* without diversity benefit;

NEC_i is the available net import capability of EIM Entity *i*, not consumed by base schedules or EIM scheduled transfers prior to the operating hour;

$TFRR$ is the total flexible ramping down requirement for the entire EIM footprint without diversity benefit (the sum of FRR_i for all BAAs in the EIM including the ISO BAA);

DB is the EIM diversity benefit: and

NI_i is the flexible ramping credit equal to the net imbalance energy import before the operating hour.

This requirement reflects a pro rata share of potential EIM diversity benefits and the flexible ramping credit, bounded from below by the available net export capability.

The Market Operator will perform a series of flexible ramping down sufficiency tests prior to commencing the EIM. The EIM Entity Scheduling Coordinator will have an opportunity to re-submit the hourly resource plan if it fails the flexible ramping down sufficiency test up to 40 minutes prior to the operating hour which is just before the start of the first financially binding EIM 15-minute market for the operating hour.

The sufficiency test will be performed for each EIM Entity BAA after T−75 minutes, T−55 minutes, and T−40 minutes for the Trading Hour starting at T. The Market Operator will use the following data to evaluate the hourly base schedule.

- Initial schedules at T−7.5'
- EIM Participating Resources energy bids and ramp rates
- 15-minute flexible ramping down requirements reduced by any diversity benefit up to available net export capability at T−7.5'

The sufficiency test is cumulative. The EIM Entity BAA must meet flexible ramping down requirements for each 15 minute interval of the hour:

Interval 1: 15-minute ramp from T−7.5 to T+7.5

Interval 2: 30-minute ramp from T−7.5 to T+22.5

Interval 3: 45-minute ramp from T−7.5 to T+37.5

Interval 4: 60-minute ramp from T−7.5 to T+52.5

Upon completion of the flexible ramping down sufficiency test, the Market Operator will enforce separate flexible ramping down constraints in the market optimization for each EIM Entity BAA, the ISO BAA, BAA group combinations, and the entire EIM footprint. EIM Entity BAAs that fail the flexible ramping down sufficiency test will not be included in any BAA group constraints; only individual constraints will be formulated for these EIM Entity BAAs for their individual flexible ramping down requirements. For the ISO BAA and the EIM Entity BAAs that pass the flexible ramping sufficiency test, individual and BAA group constraints will be formulated for the flexible ramping down requirement of the group, reduced by the available net export capability into that group. The flexible ramping requirements for BAA groups can be potentially lower than the individual requirements of each BAA in the group, reflecting the benefits of reduced uncertainty and volatility across the BAA group. By considering the available net export transfer capability in the individual and BAA group constraints, the market optimization can select the most efficient resources across the EIM footprint to meet both the individual BAA requirements and the system requirement.

To illustrate the proposal, consider the following example where the base schedules and initial EIM transfers are assumed zero for simplicity:

BAA	**Flexible Ramping Requirement (MW)**	**Flexible Ramping Requirement with diversity benefit (MW)**	**Flexible Ramping Sufficiency Test**
ISO	300	N/A	N/A
EIM_1	200	$200 \times 600 / 650 = 184.62$	✓
EIM_2	150	$150 \times 600 / 650 = 138.46$	✗
ALL	650	600	

TABLE 160 – FLEXIBLE RAMPING SUFFICIENCY TEST RESULTS

The flexible ramping down requirements used in the flexible ramping down sufficiency test for each BAA considers the EIM diversity benefits. EIM_1 passes the flexible ramping down sufficiency test, whereas the test fails for EIM_2. The available power transfer capability between the participating BAAs does not limit diversity benefits and is as follows:

	ISO	EIM_1	EIM_2
ISO		80	80
EIM_1	80		20
EIM_2	80	20	

TABLE 21 – AVAILABLE POWER TRANSFER CAPABILITY BETWEEN BAAS

Since EIM_2 fails the flexible ramping down sufficiency test, it will be isolated from the rest of the EIM, i.e., there will be no net imbalance energy export out of that BAA. It is important to note that the flexible ramping up and flexible ramping down sufficiency tests are distinct. An EIM Entity could fail the flexible ramping down test and pass the flexible ramping. In this scenario, the EIM Entity will be restricted from additional EIM transfers into its BAA, but not be restricted from additional EIM transfers out of its BAA.

Continuing with the example, the flexible ramping constraints limits will be as follows:

BAA	Minimum Flexible Ramping Capacity Limit (MW)
ISO	200 = 300 – 80 – 20
EIM_1	100 = 200 – 80 – 20
EIM_2	150*
ISO+ EIM_1	500 = 300 + 200

TABLE 22 – MARKET OPTIMIZATION CONSTRAINT LIMITS – EIM_2 FAILS TEST

The flexible ramping down constraint for EIM_2 will probably not be satisfied, hence it will be relaxed with the price reflecting such scarcity; however, it will still be enforced at the relaxed limit to reduce the likelihood of scarcity in EIM_2. The minimum flexible ramping down capacity limits for the ISO and EIM_1 are reduced by the 100 MW available net power transfer capability between these areas, allowing for a 20 MW loop flow through EIM_2. The minimum flexible ramping down capacity limit for both areas effectively allows the requirement in one area to be met by resources in the other area, but only within the available net power transfer capability.

If EIM_2 had passed the flexible ramping sufficiency test, the flexible ramping down capacity constraints limits would have been as follows:

BAA	Minimum Flexible Ramping Capacity Limit (MW)
ISO	140 = 300 – 80 – 80
EIM_1	100 = 200 – 80 – 20
EIM_2	50 = 150 – 80 – 20
ISO+ EIM_1	400 = 300 + 200 – 80 – 20
ISO+ EIM_2	350 = 300 + 150 – 80 – 20
EIM_1+ EIM_2	190 = 200 + 150 – 80 – 80
ALL	600

TABLE 23 – MARKET OPTIMIZATION CONSTRAINT LIMITS – ALL BAAS PASS TEST

This example shows the benefits of EIM participation to reduce uncertainty and volatility across the EIM footprint utilizing the available net power transfer capability across the EIM BAAs.

8.2 ALLOCATION OF CONSTRAINTS TO EACH BAA

As with the initial implementation of EIM, the ISO will calculate a total BAA cost for the flexible ramping products before performing the cost allocation to the three categories. Once the BAA level costs are calculated, the ISO will perform the same cost allocation within each of the three categories. As a result, EIM Participating Resource Scheduling Coordinators will be allocated directly their share of the EIM Entity BAA flexible ramping costs. All resources in the EIM footprint will be allocated similarly. The cost allocation of the flexible ramping product is a key design element as it seeks to increase market compensation of flexible resources while decreasing the net market compensation of inflexible resources.

The ISO will calculate a total cost of each constraint. The total cost of each constraint will consider the rescission of flexible ramping payments to resources which fail to perform. For shared constraints, the total cost for the constraint will be divided pro-rata based upon the individual BAA requirements. For example, the ALL constraint in Table 23 would be allocated 46% (300/650) to the ISO, 31% to EIM_1 (200/650), and 23% to EIM_2 (150/650). The same approach has been implemented with the flexible ramping constraint.

Unlike the flexible ramping constraint which is only enforced in the real-time unit commitment process and compensated in the fifteen-minute market, the flexible ramping product is enforced in the ISO's day-ahead market and both the fifteen-minute market and RTD in the real-time market. In addition, if a resource which has an award in a previous market is scheduled or dispatched for energy, the resource buys back their flexible ramping award. The sum of payments less buy backs in the day-ahead market, 15-mintue market and RTD will be included in calculating the total costs of each constraint. In the day-ahead market, only the ISO constraint is enforced; however, resources that are awarded flexible ramping in day-ahead may be used to meet EIM constraints if economic to do so. Therefore, the day-ahead procurement costs should be applied to the combined EIM constraints.

9. PLAN FOR STAKEHOLDER ENGAGEMENT

Item	Date
Post Revised Straw Proposal	August 13, 2014
Stakeholder Meeting	August 20, 2014
Stakeholder Comments Due	September 3, 2014
Post Draft Final Proposal	September 23, 2014
Stakeholder Conference Call	September 30, 2014
Stakeholder Comments Due	October 14, 2014
Board of Governors Meeting	December 18-19, 2014

10. NEXT STEPS

The ISO will hold a stakeholder meeting on August 20, 2014. The ISO is seeking written comments by September 3, 2014. Stakeholder comments should be sent to FRP@caiso.com.

APPENDIX A: NOMENCLATURE

MCG market clearing granularity: day-ahead 60 minutes, RTUC 15 minutes, and RTD 5 minutes

AF averaging factor = $MCG/5$: day-ahead 12, RTUC 4, and RTD 1

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

$FRU_{i,t}^{RU}$ upward flexible ramping from resource i's extra available regulation-up capacity at time interval t

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

$FRD_{i,t}^{RU}$ downward flexible ramping from resource i's extra available regulation-down capacity 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

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

$FRUP_t$ shadow price of upward flexible ramping constraint at time interval t

$FRDP_t$ 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 stylized/simplified model in this section is for illustration purpose only, and may not reflect the actual implementation model. The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[6] 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,[7] 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.

Upward ramping capability limit: This constraint ensures that a resource's upward ramping award plus the total amount of upward reserves (regulation-up, spinning, and non-spinning) awards does not exceed its upward ramping capability over the market clearing interval.

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

Downward ramping capability limit: This constraint ensures that a resource's downward ramping award plus the regulation-down award does not exceed its downward ramping capability over the market clearing interval.

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

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.

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

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[6] 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.

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

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.

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

Upward flexible ramping requirement: This constraint ensures that the total amount of upward flexible ramping product awards meets the requirement over the market clearing interval.

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

Downward flexible ramping requirement: This constraint ensures that the total amount of downward flexible ramping product awards meets the requirement over the market clearing interval.

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

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[8].

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.

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