Flexible Ramping Products

Second Revised Draft Final Proposal

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Table of Contents

1. Introduction 3
2. Flexible ramping products design 8
   2.1 Flexible ramping products Bidding rules 9
      2.1.1 Flexible ramping Bid cap and floor 10
      2.1.2 Flexible ramping self provision 10
      2.1.4 Flexible ramping market power mitigation 10
   2.2 Co-optimizing flexible ramping products with energy and ancillary services 11
   2.3 Flexible ramping requirement and demand curve 12
   2.4 Model flexible ramping in look-ahead optimization 18
   2.5 Day-ahead Market procurement 19
      2.5.1 Merging IFM and RUC 19
      2.5.2 Integrated Day-ahead market flex ramp procurement 20
      2.5.3 Two settlement system 22
   2.6 Settlement of flexible ramping products 22
      2.6.1 Flexible ramping award settlement 22
      2.6.2 Flexible ramping no pay settlement 23
3. Flex ramp Examples 26
   3.1 Properties of flex ramp 27
      3.1.1 Upward flex ramp 27
      3.1.2 Downward flex ramp 31
   3.2 An settlment example 35

4. Other design elements 36

4.1 grid management charges 36

4.2 Flexible Ramping Product data release 36

5. PIRP DEC Bidding 36

6. Cost Allocation 38

6.1 Proposed Movement Baseline for Flexible Ramping Product 39

6.2 Billing Determinant of Load Category 42

6.3 Billing Determinant of Supply Category 43

6.3.1 Baseline to Measure Deviations for Conventional Resources 44

6.3.2 Baseline to Measure Deviations for Variable Energy Resources 45

6.3.3 Threshold for Allocation 46

6.4 Billing Determinant of Fixed Ramp Category 46

6.5 Cost Allocation Granularity within the Day 47

6.6 Monthly Re-Settlement 48

6.7 Assignment of Flexible Ramping Cost Allocation 48

Plan for Stakeholder Engagement 48

Next steps 48

Appendix A: Nomenclature 49

Appendix B: Co-optimizing flexible ramping products with energy and ancillary services 51

Appendix C: Modeling ancillary services with operational ramp rate 53

1. INTRODUCTION

This paper will describe the ISO's proposal to define the upward and downward flexible ramping products. The purpose of this stakeholder effort is to develop market-based flexible ramping products to address the operational challenges of maintaining power balance in real-time markets. 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 delivery 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 ISO has to pay the imbalance energy from the regulation services the administrative penalty prices from RTD.
- If there is insufficient regulation service, the result of insufficient ramping capability may result in leaning on interconnection, which may affect the ability to meet required operational performance criteria.

Since the new nodal market was implemented in 2009, the ISO has modeled multi-interval optimization in the unit commitment and dispatch process. The multi-interval optimization can look several intervals ahead to meet forecasted ramping need. The ISO has observed that the optimization will often create exactly the same amount of ramping capacity according to the 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 on the between interval ramping need in a multi-interval optimization, and any deviation beyond the forecasted ramping need may incur a power balance violation. The purpose of the flex ramp product to be developed in this proposal is to create ramping margin on top of the forecasted between interval ramping need, and thus reduce the frequency of power balance violations.

With increasing level of renewable penetration, 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.

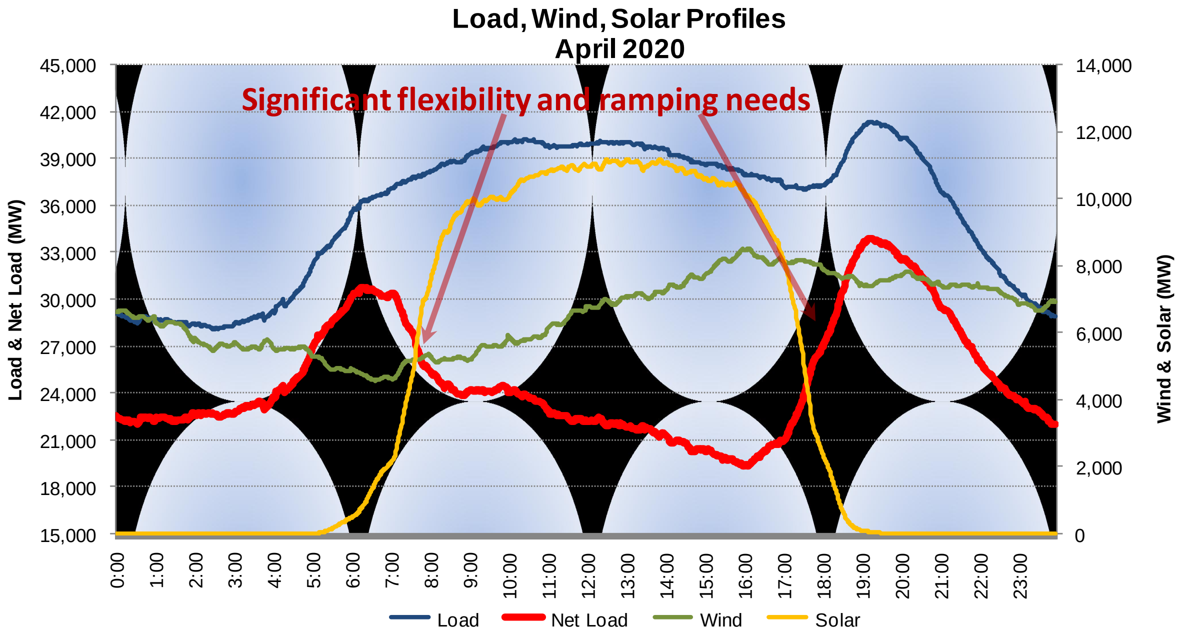

FIGURE 1: PROJECETED LOAD AND RENEWABLE PROFILES IN APRIL 2020[1]

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 type of uncertainties is realized before the binding RTD dispatch, and the other type of uncertainties is realized after the binding RTD dispatch. Moreover, uncertainties realized before the binding RTD dispatch have impact on the system conditions and the RTD energy price in the binding RTD, 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 operational point of view, more regulation procurement can also handle uncertainties realized before the binding RTD dispatch. However, from the market 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 the regulation service and cannot be accessed 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 ISO needs to pay the dispatched energy 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. Flexible ramping product is the new market product to take care of uncertainties realized before the binding RTD dispatch. Flex ramp 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.

Stakeholder also questioned whether procuring more non-contingent spinning reserve would be able to achieve what the flex ramp product can do. 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 compensation point of view.

Prior to these market-based full flexible ramping products, the ISO has proposed to implement a flexible ramping constraint to address certain reliability and operational issues observed in the ISO's operation of the grid.[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 effectiveness 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 to be developed will help the system to maintain and use dispatchable flexibility in terms of ramping capability. 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 change, 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 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 systems 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 to t–2). 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 product 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 consists of 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 }

[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

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.

Stakeholders have questioned why the procurement target is real ramping need, not the unexpected ramping need on top of the expected ramping. The argument goes in the direction 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 flex ramp. It is inappropriate to treat and compensate the resources under the two categories differently.

Stakeholder also questioned why cycling of generation resources are not considered in the flex ramp day-ahead procurement in the October 19, 2012 Market Surveillance Committee meeting. 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 flex ramp 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 have certain ramping capability in certain regions. If a regional flexible ramping requirement constraint is binding, the regional flexible ramping cost will be allocated in the corresponding region. The regional procurement details are out of the scope of this proposal.

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

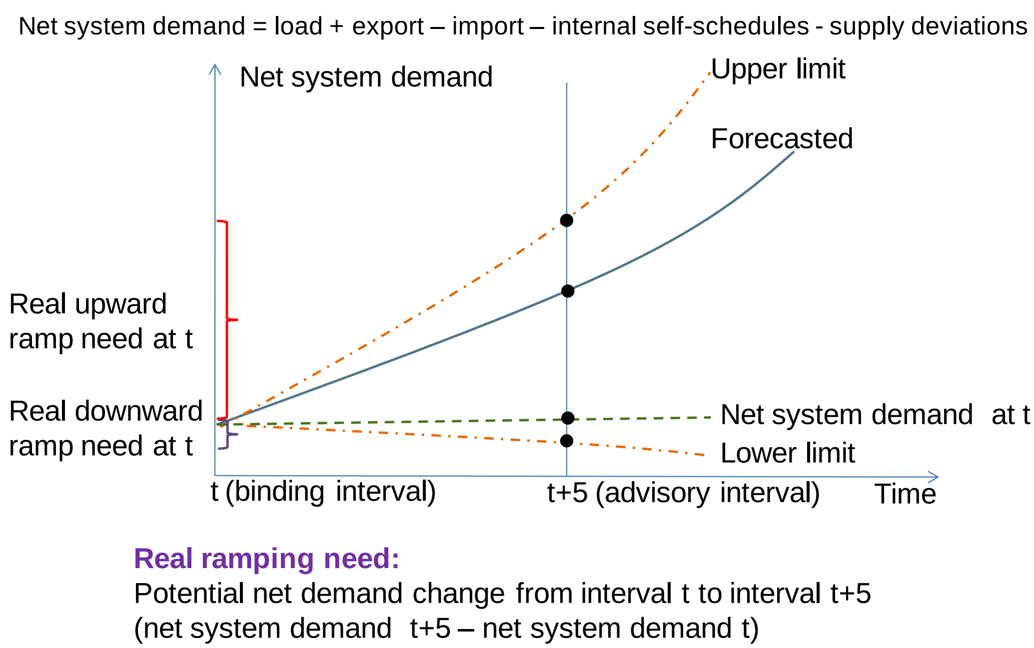

FIGURE 2: REAL RAMPING NEED

The major changes in the revised draft final proposal from the draft final proposal include:

1. Only allow flex ramp capacity bids in day-ahead. Do not allow flex ramp capacity bids in real-time.

2. Eliminated bidding rule that flex ramp bid price should be no higher than regulation, and eliminate regulation participates as flex ramp.

3. Clarified that in market operations the ISO will forecast the high (97.5% percentile) net load and low (2.5% percentile) net load to set the maximum requirement. The maximum requirement is not set at the historical 95% variation of the net system demand.

4. Eliminated the constraint that RUC schedule is no less than the IFM schedule in combined IFM and RUC.

5. Added flex ramp down examples.

2. FLEXIBLE RAMPING PRODUCTS DESIGN

In this section, we will cover the flexible ramping product design. The discussion will be focus on real-time markets because the product is aiming at improving real-time market dispatch flexibility. However, procuring some of the ramping capability in the day-ahead market may provide benefits. One benefit of modeling flexible ramping products in IFM is to make unit commitment decision for long start units and establish forward financial position for flexible ramping capability. We will discuss the design elements to accommodate the day-ahead procurement in Section 2.5.

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, flexible ramping product is the only market product targeting at between interval net system demand changes.

Dispatched in RTD on a regular basis Flexible ramping product is the 5-minute ramping capability continuously being procured and dispatched in RTD to meet the net system movement. No similar capacity product exists in the ISO's current market now. 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. Similar to energy dispatch, the flexible headroom is not binding in RTUC. The ISO will bindingly procure flexible ramping capability in RTD because RTD produces binding energy dispatches from where the ramping capability is evaluated. The flexible ramping products awards will be compensated according to the marginal prices in RTD where the energy awards are also financially binding.

2.1 FLEXIBLE RAMPING PRODUCTS BIDDING RULES

Capacity bids for flex ramp are not allowed in the real-time market, because any operational cost for providing the ramping capability is foregone when the resource offers energy into the real-time market. The flex ramp price will be purely based on opportunity cost as the current flex ramp constraint. The ISO will only award flex ramp to RTD dispatchable resources that makes an energy offer to the market.

The day-ahead market will accept separate capability bids on upward flexible ramping product and downward flexible ramping product, which express the resources' operational cost associated with providing such flexible ramping capability. The cost should not include investment cost, wear and tear cost or opportunity cost from energy limitation[4], but may include the opportunity cost of offering the capacity into the ISO market vs offering the capacity outside the ISO. The upward capability bid can be different from the downward capability bid. A resource must have an economic energy bid to back up the flexible ramping capability. If a resource does not have an explicit flexible ramping bid, it is assumed to have zero cost to provide flexible ramping.

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

2.1.1 FLEXIBLE RAMPING BID CAP AND FLOOR

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

2.1.2 FLEXIBLE RAMPING SELF PROVISION

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.

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

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

This section will cover the stylized optimization model of co-optimizing the flexible ramping products with energy and ancillary services. The 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 ramping constraints in each interval of RTUC and RTD.[5] Modeling flexible ramping products in advisory intervals enable the optimization to foresee potential problems in the future, and take actions accordingly.

The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[6] 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.

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.

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[5] 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.

[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.

Flexible ramping product is 5-minute ramping capability based on the dispatch level and the resource's ramp rate. Day-ahead market and real-time markets 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 = 4 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 RTD flexible ramping award the DA 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. This is because evaluated on an hourly basis, there is no difference between the two resources' 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.

2.3 FLEXIBLE RAMPING REQUIREMENT AND DEMAND CURVE

The ISO will buy flexible ramping product to cover 95% of confidence level of between interval net system demand changes. The ISO will forecast the 2.5% percentile and 97.5% percentile of the net system demand changes.

The upward maximum requirement and the downward maximum requirement is

upward maximum requirement = max{97.5% percentile, 0}

downward maximum requirement = max{–2.5% percentile, 0}.

For example if the 2.5% percentile is –100 MW, then the downward maximum requirement is 100 MW; if the 2.5% percentile is 10 MW, then the downward maximum requirement is 0 MW. Similarly, if the 97.5% percentile is 150 MW, then the upward maximum requirement is 150 MW; the 97.5% percentile is –50 MW, then the upward maximum requirement is 0 MW.

To provide an estimate of the maximum procurement level for flex ramp, the ISO performed historical analysis on the net system demand changes from January to March 2012, and calculated the 2.5% percentile and 97.5% percentile of the average 5-minute net system demand change for 24 hours. This is illustrated in Figure 3, where the blue bar is the 2.5% percentile and the red bar is the 97.5% percentile. We stress that the purpose of this analysis is only to estimate the maximum flex ramp procurement level. The ISO does not intend to use this historical analysis to set the procurement target in market operations. The ISO has developed more sophisticated forecasting tool to feed the market applications.

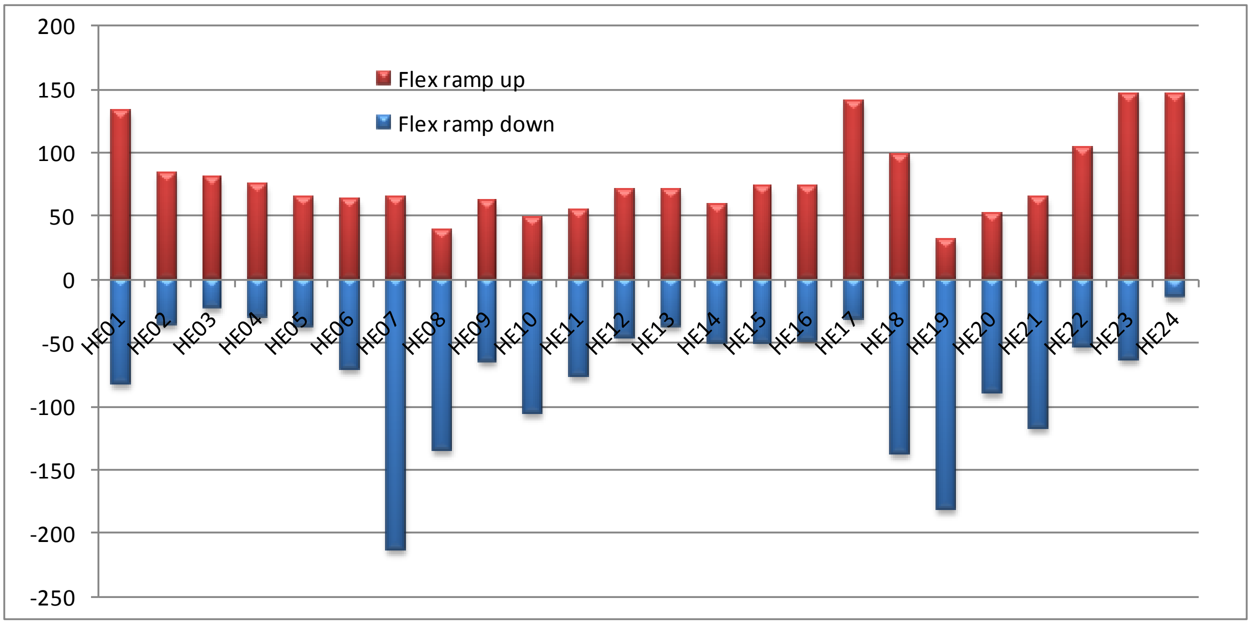

FIGURE 3: SAMPLE FLEXIBLE RAMPING MAXIMUM REQUIREMENT (95% CONFIDENCE INTERVAL)[7]

The minimum requirement for flexible ramping is the expected net system movement between the energy binding 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 4 and Figure 5. The penalty price for violating the minimum requirement is equal to the bid cap $250.

The minimum requirement and the maximum requirement is 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:

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[7] These values are comparable to the 5 minute upward requirement procured in RTD under the flex ramp constraint which has ranged from 150MW-225MW.

- the distribution of power balance violations
- the penalties of power balance violations

The distribution of power balance violations can be analyzed with historical data. The penalties of power balance violations will be assigned based on the penalties used in the market optimization, which captures the risk of lost load or over gen. This method provides a simple and transparent way to construct the demand curve for flex ramp.

The power balance violation (PBV) distribution without the flexible ramping product[8] from January 2011 to March 2011 is listed in Table 1. The PBV distribution with flex ramp can be derived by shifting MWs. For example, the PBV probability from 0-100 MW with 100 MW of flex ramp, 0.25%, is equal to the PBV probability from 100-200 MW with 0 MW flex ramp. The average violation MW with 100 MW of flex ramp is 100 MW less than the average violation MW with 0 MW flex ramp. This is because 100 MW of flex ramp would be able to reduce PBV by 100 MW. The PBV distribution without flex ramp may not be available after implementing the flex ramp product. In this case, the ISO has to perform analyses to estimate the distribution.

PBV category	0 MW flex ramp		100 MW flex ramp		200 MW flex ramp		300 MW flex ramp	
	Prob.	Avg.	Prob.	Avg.	Prob.	Avg.	Prob.	Avg.
–200-0MW	2.67%	100.00	1.34%	50.00	0	0	0	0
0-100 MW	0.47%	48.27	0.25%	47.29	0.09%	50.22	0.28%	47.79
100-200 MW	0.25%	147.29	0.09%	150.22	0.28%	147.79	0%	0
200-300 MW	0.09%	250.22	0.28%	247.79	0%	0	0%	0
300-400 MW	0.28%	347.79	0%	0	0%	0	0%	0

TABLE 1: POWER BALANCE VIOLATION PROBABILITY DISTRIBUTION WITH AVAILABLE FLEX RAMP

Power balance violation may cause the system to lean on regulation, and impose a reliability risk on the grid. Therefore, we should assign penalties for power balance violations to prevent it from happening often. Assume we assign power balance violation penalties as in Table 2, which are interpolated from the power balance penalties in the market[9].

Then we can calculate the value of flexible ramping as follows. First, we calculate the total penalty cost to the system with 0 MW flex ramp, 100 MW flex ramp, 200 MW flex ramp, and 300 MW flex ramp respectively. Then we calculate the per MW marginal value the first 100 MW upard flex ramp as

[8] The market application only reports the over generation event, but not the over generation amount. We assume the over generation amount is uniformly distributed from 0 MW to 200 MW.

[9]Currently, the under generation penalty in the market is $1000 for blow 350 MW violation and $6500 for above 350 MW violation. The over generation penalty in the market is –$30 now, and will be changed to –$150 and then –$300 in the future.

(penalty cost0 – penalty cost100)/100 = (8745.65 – 3986.76)/100 = $47.59/MWh.

Similarly, the per MW marginal value of the second 100 MW upward flex ramp is

(penalty cost100 – penalty cost200)/100 = (3986.76 – 1289.65)/100 = $26.97/MWh.

The per MW marginal value of the second 100 MW upward flex ramp is

(penalty cost200 – penalty cost300)/100 = (1289.65 – 134.35)/100 = $11.55/MWh.

All the calculations above are listed in detail in Table 3.

Similarly, the downward flex ramp marginal value calculation is listed in Table 4. The upward and downward demand curves are summarized in Table 5.

Power balance violation	Penalty
–200-0 MW	–$150
0-100 MW	$1000/MWh
100-200 MW	$3000/MWh
200-300 MW	$5000/MWh
300-400 MW	$6500/MWh

TABLE 2: POWER BALANCE VIOLATION PENALTIES

Upward	0 MW flex ramp	100 MW flex ramp	200 MW flex ramp	300 MW flex ramp
PBV category	Penalty cost0	Penalty cost100	Penalty cost200	Penalty cost300
0-100 MW	228.08	0	0	0
100-200 MW	1087.06	116.35	0	0
200-300 MW	1074.77	387.14	43.14	0
300-400 MW	6355.73	3483.27	1246.51	134.35
Sum cost	8745.65	3986.76	1289.65	134.35
Flex ramp value	N/A	47.59	26.97	11.55

TABLE 3: UPWARD FLEX RAMP VALUE

Downward	0 MW flex ramp	100 MW flex ramp	200 MW flex ramp	300 MW flex ramp
PBV category	Penalty cost0	Penalty cost100	Penalty cost200	Penalty cost300
–200-0 MW	400.05	200.03	0	0

Flex ramp value	N/A	2.00	2.00	0

TABLE 4: DOWNWARD FLEX RAMP VALUE

The complete demand curve is as follows

Demand curve	MW	Price
Downward	–200-0 MW	$2.00/MWh
Upward	0-100 MW	$47.59/MWh
	100-200 MW	$26.97/MWh
	200-300 MW	$11.55/MWh

TABLE 5: UPWARD AND DOWNWARD FLEXIBLE RAMPING DEMAND CURVE

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 4 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 5. 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.

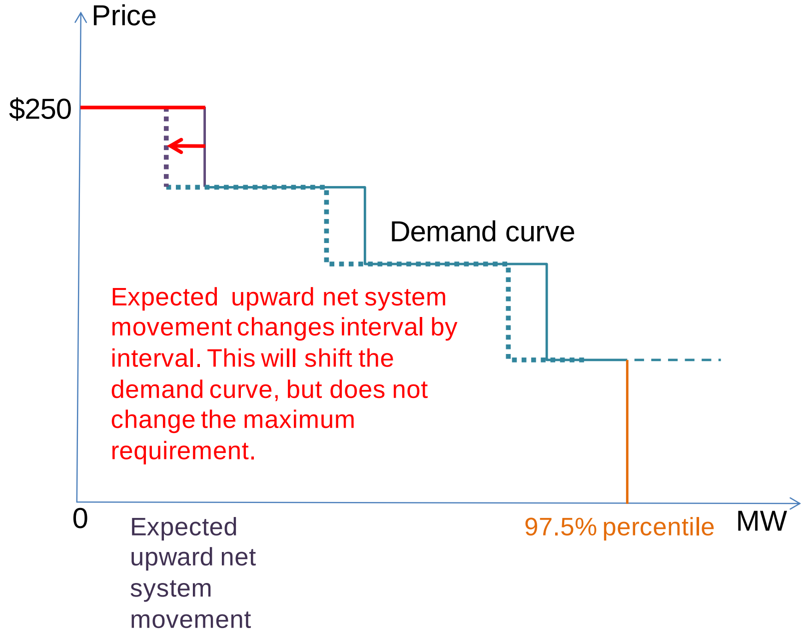

FIGURE 4: UPWARD FLEXIBLE RAMPING REQUIREMENT CURVE WITH UPWARD EXPECTED NET SYSTEM MOVEMENT)

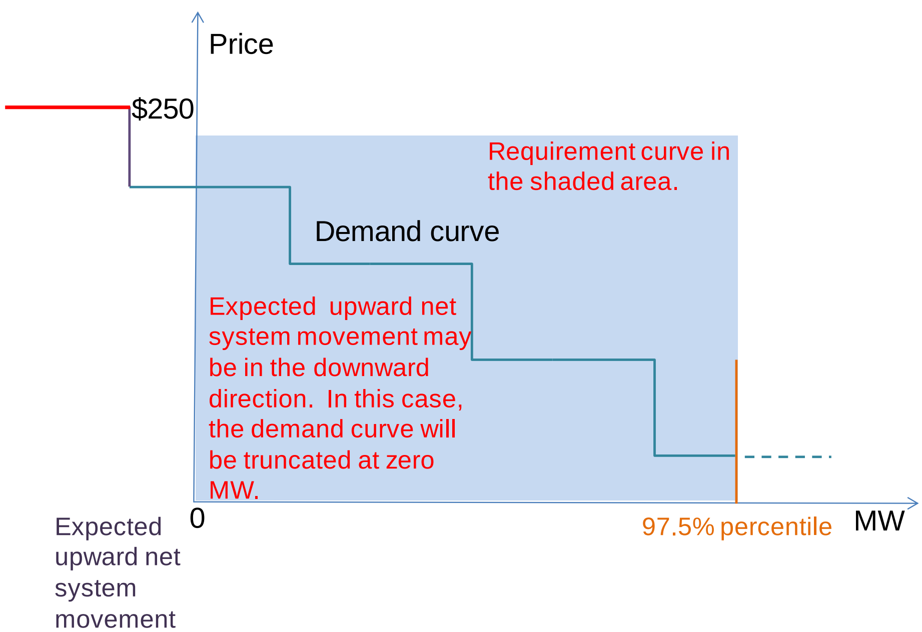

FIGURE 5: UPWARD FLEXIBLE RAMPING REQUIREMENT CURVE WITH DOWNWARD EXPECTED NET SYSTEM MOVEMENT

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 okay to buy more flexible ramping; otherwise, it is better to take some risk of price volatility and buy less 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 kept again in interval t to meet interval t flexible ramping requirement, or can be kept for fewer amount, and release some for dispatch in interval t. If the energy supply is tight in interval t, the tight energy supply will compete for capacity again flex ramp, and cause the flex ramp price to increase. The ramping capability, which has a higher cost than the flex ramp 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 flex ramp or dispatching the capacity as energy.

2.4 MODEL 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 flex ramp can do in driving the dispatch. However, the prices resulting from the multi-interval optimization may be more volatile and less efficient than modeling flex ramp as will be demonstrated in section 3.

With flex ramp being modeled in real-time markets, the flex ramp 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 6. Figure 6 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.

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.

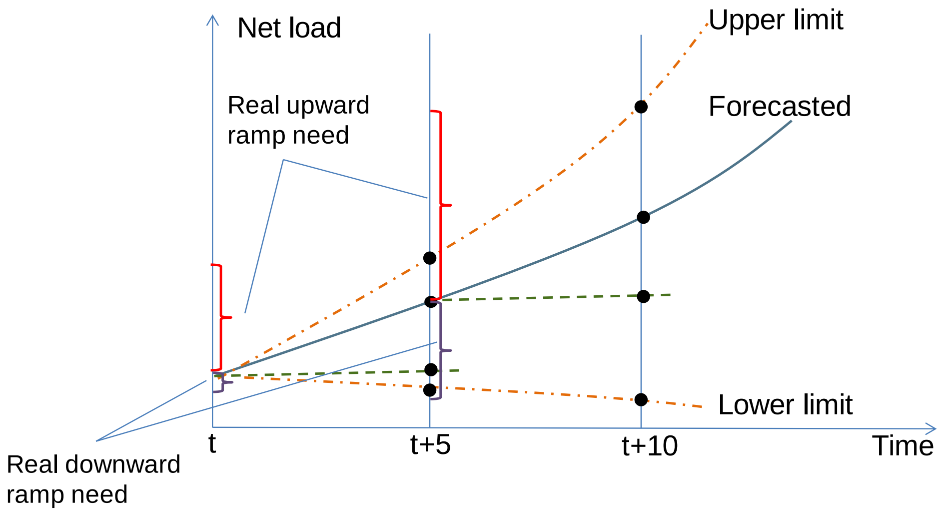

FIGURE 6: REAL RAMP NEED IN LOOK-AHEAD OPTIMIZATION

2.5 DAY-AHEAD MARKET PROCUREMENT

In this section, we will cover the design elements to accommodate day-ahead flexible ramping procurement.

2.5.1 MERGING IFM AND RUC

Currently the day-ahead market consists of two separate market optimizations. One is the integrated forward market (IFM), which clears energy schedules including both physical and virtual schedules, and procures ancillary services. The other is reliability unit commitment (RUC), which commits additional capacity to meet physical load forecast. With the flexible ramping product to deal with physical dispatch problem, it is necessary to model the correct pool of physical resources that can provide the ramping capability. In other words, the pool should not be limited to the physical resources committed in the IFM, but also should include the resources committed in RUC. Therefore, we expect to improve market efficiency if the IFM and RUC are merged to produce a co-optimized solution.

The integrated Day-Ahead Market (iDAM) combines the functionality IFM and RUC into a single market application. Besides unit commitment, the commodities procured in iDAM are the following:

- Day-Ahead Energy schedules for physical and virtual resources;
- Day-Ahead Reliability schedules, capacities, and awards for physical resources;
- Day-Ahead Regulation Down awards;
- Day-Ahead Mileage Down awards;
- Day-Ahead Regulation Up awards;
- Day-Ahead Mileage Up awards;

- Day-Ahead Spinning Reserve awards;
- Day-Ahead Non-Spinning Reserve awards;
- Day-Ahead Flexible Ramp Down awards;
- Day-Ahead Flexible Ramp Up awards; and
- Day-Ahead Transmission capacities and reservation awards for Dynamic Transfers.

The unit commitment solution allows both balancing of supply and demand bids and meeting the demand forecast. This can be accomplished by enforcing two power balance constraints:

1) Physical and virtual Energy supply schedules balance physical and virtual Energy demand schedules and transmission losses; and
2) Physical Reliability supply and dispatchable demand schedules balance the demand forecast including transmission losses.

The objective function is the maximization of the total merchandizing surplus including the following:

- the cost from scheduled Energy supply bids;
- the benefit from scheduled Energy demand bids;
- the Start-Up, Minimum Load, and State Transition Cost of committed resources;
- the cost from awarded Ancillary Services bids;
- the benefit from awarded Transmission capacity reservation bids; and
- the cost from awarded Reliability (previously awarded in RUC) capacity bids.

Energy and Reliability schedules are constrained by separate linearized network constraints (for both base case and contingencies) derived from separate AC power flow solutions. These schedules and the Ancillary Services awards are also simultaneously constrained by resource capacity and ramping constraints, similarly to the current IFM and RUC.

The Day-Ahead Market Power Mitigation (MPM) is a "trial" run of iDAM with unmitigated bids. Then the mitigated bids will be used in iDAM.

The iDAM is essentially a consolidation of existing and planned market functionality, rather than a market redesign effort. Nevertheless, as part of the stakeholder process, certain market design aspects may be reexamined with the goal of increasing efficiency, transparency, and simplicity.

2.5.2 INTEGRATED DAY-AHEAD MARKET FLEX RAMP PROCUREMENT

With combined IFM and RUC, flex ramp will be procured in this integrated market to cover between interval potential net system demand movement as illustrated in Figure 7. In Figure 7, the ISO has forecasted the real-time net system demand, which is the RUC target. The ISO has also forecasted the error band around the RUC target ranging from the lower limit to the upper limit. Flex ramp is to cover the potential net demand change between hour h and hour h+1

- Upward: max{ [upper limit in hour h+1] – [net system demand forecast in hour h], 0 }
- Downward: max{ [net system demand forecast in hour h] – [lower limit in hour h+1], 0 }.

This is consistent with how we procure flex ramp in real-time except the market clearing granularity difference.

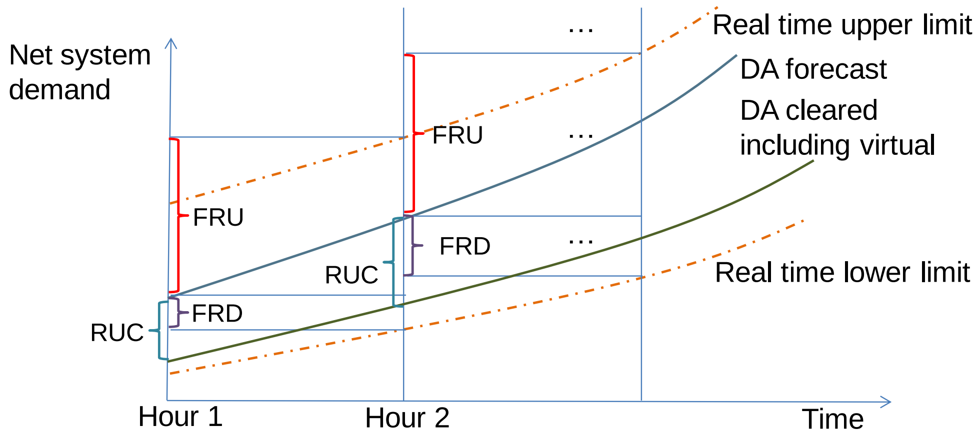

FIGURE 7: DAY-AHEAD MARKET FLEX RAMP PROCUREMENT

The following is a simplified example for RUC and flex ramp requirement. In this example, renewable resources schedule 1000 MW in DA, but in real-time they can vary from 1000 MW to 3000 MW. Assume the renewable forecast is 2000 MW. Bid-in load clears at 10000 MW, which is 2000 MW less than the load forecast 12000 MW. Self schedules are the same 2000 MW in both IFM and RUC. The RUC net load is 12000(load forecast)-2000(wind forecast)-2000(self schedule) = 8000 MW. The IFM net load is 10000(cleared load)-1000(wind schedule)-2000(self schedule)-200(virtual gen)=6800 MW. So RUC needs to get additional 8000-6800=1200 capacity.

In RT, load varies from 11500 to 12500 in the next hour, and renewable can vary from 1000 to 3000 in the next hour. In this case, the net load variation is 3000 MW in total including 1000 MW from load variation and 2000 MW from wind variation. The flex ramp up and flex ramp down should sum to 3000 MW in order to cover the 3000 MW net load variation. Where do they split depends on where the RUC target is, and where the lower limit and upper limit are.

RT lower limit = 11500(low load)-3000(high renewable) – 2000 (self schedule) = 6500,

RT upper limit = 12500(high load)-1000(low renewable) – 2000 (self schedule) = 9500.

So the hourly FRU requirement is 9500-8000=1500, and the hourly FRD requirement is 6500-8000=–1500 (as a convention negative number means downward). They will be converted to 5 minute requirements by dividing by 12.

	IFM	RUC	RT lower limit	RT upper limit
load	10000	12000	11500	12500
renewable	1000	2000	3000	1000
self schedule	2000	2000	2000	2000

net virtual gen	200	0	0	0
Net demand	6800	8000	6500	9500
Requirement		RUC	FRD	FRU
		1200	-1500	1500

TABLE 6: DAY-AHEAD FLEX RAMP PROCUREMENT EXAMPLE

2.5.3 TWO SETTLEMENT SYSTEM

Similar to energy, flexible ramping will be settled through a two settlement system. Day-ahead flexible ramping award will be settled at the day-ahead flexible ramping price. The difference between the RTD flexible ramping award and the day-ahead flexible ramping award will be paid the RTD flexible ramping price.

A resource with day-ahead flex ramp award may be dispatched for energy in RTD. In this case, the resource needs to pay back the unavailable flex ramp capacity at the RTD price. Any capacity will be only paid once, either for flex ramp capacity. In addition, allowing economic buyback in RTD can resolve double payment issue that may arise due to the granularity difference between IFM and RTD. In the IFM, 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 real-time 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 real-time) 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 RTD at the RTD price.

2.6 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

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

2.6.1 FLEXIBLE RAMPING AWARD SETTLEMENT

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

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

2.6.2 FLEXIBLE RAMPING NO PAY SETTLEMENT

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

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

Details about each of the categories will be discussed below.

A resource with flexible ramping awards is illustrated in Figure 8. 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.

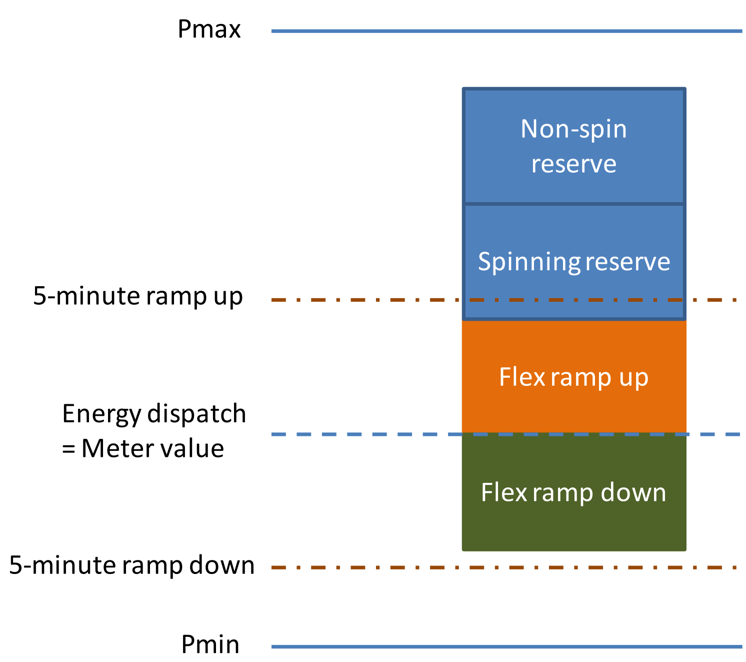

FIGURE 8: A RESOURCE WITH NO FLEXIBLE CAPCITY PAYMENT RECISSIONS

- **Undispatchable Capability** – There are two subcategories of Undispatchable Capability:
    - **Availability-Limited Capability** – If a resource's capability is re-rated in real-time, the total amount of flexible ramping Awards may not be available in Real-Time for dispatch due to the availability limitation. This is illustrated in Figure 9, 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.

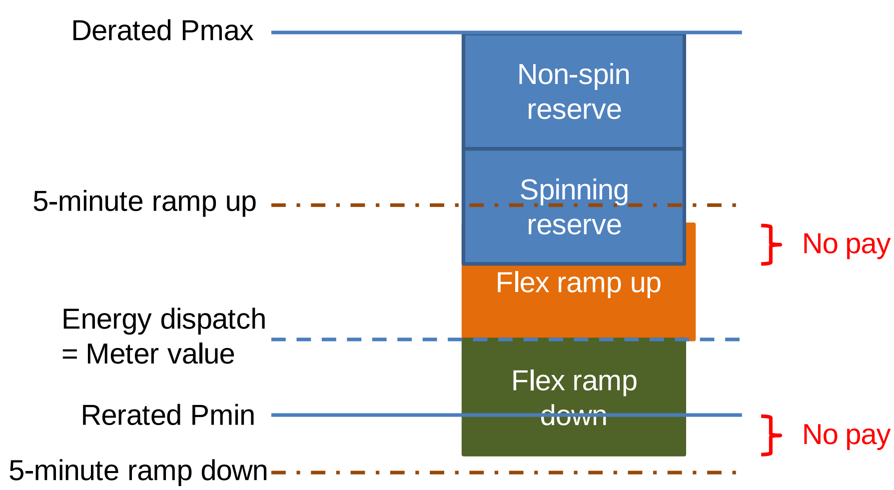

FIGURE 9: A RESOURCE WITH UNAVAILABLE FLEXIBLE RAMPING CAPABILITY NO PAY

- **Ramp-Limited Capability** – Flexible ramping are required to be delivered in 5 minutes. If a resource does not have the 5-minute Ramp Rate capability in Real-Time to deliver the flexible ramping awarded, then a portion of the flexible ramping capability is not available due to the Ramp Rate limitations on the resource. This is illustrated in Figure 10.

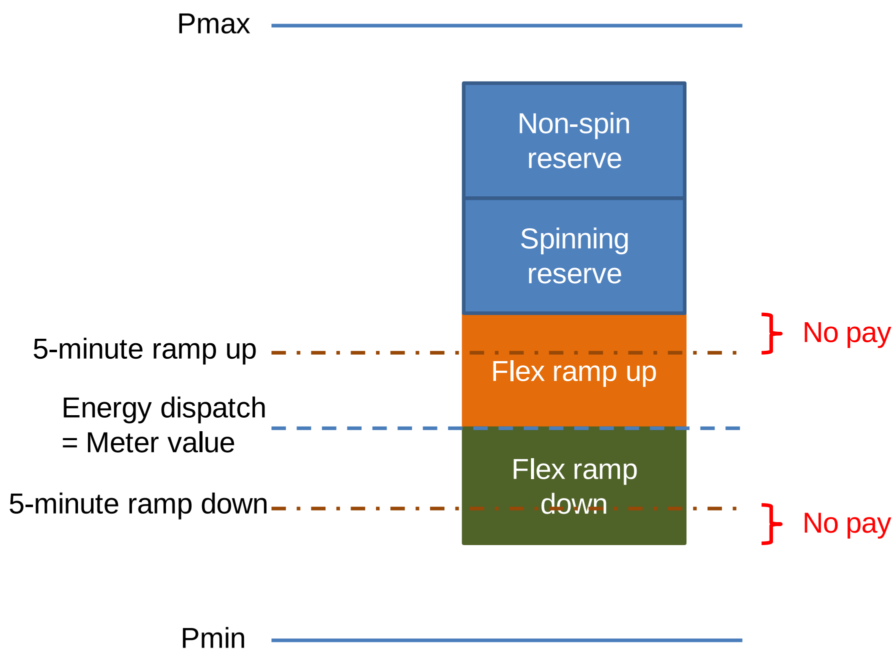

FIGURE 10: A RESOURCE WITH RAMP-LIMITED NO PAY

- **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 11.

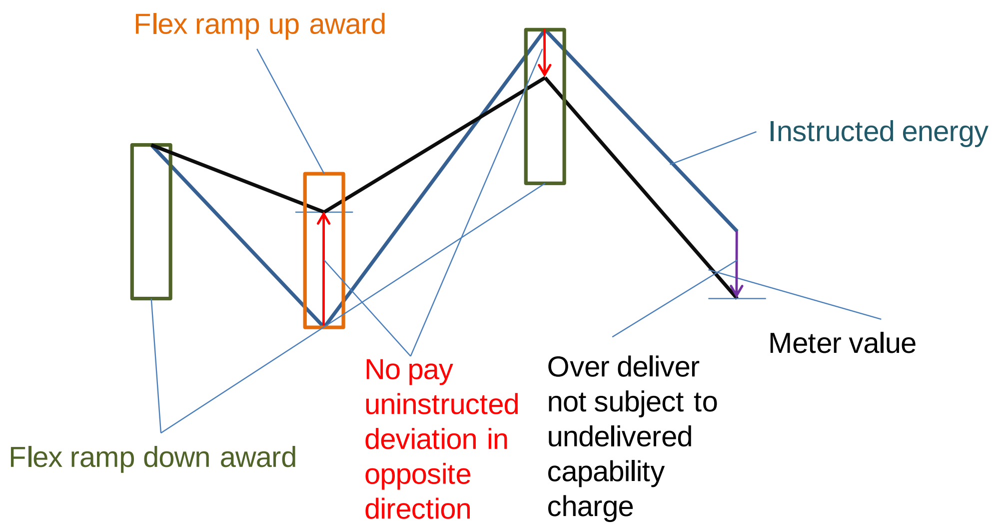

FIGURE 11: UNDELIVERED CAPABILITY NO PAY

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

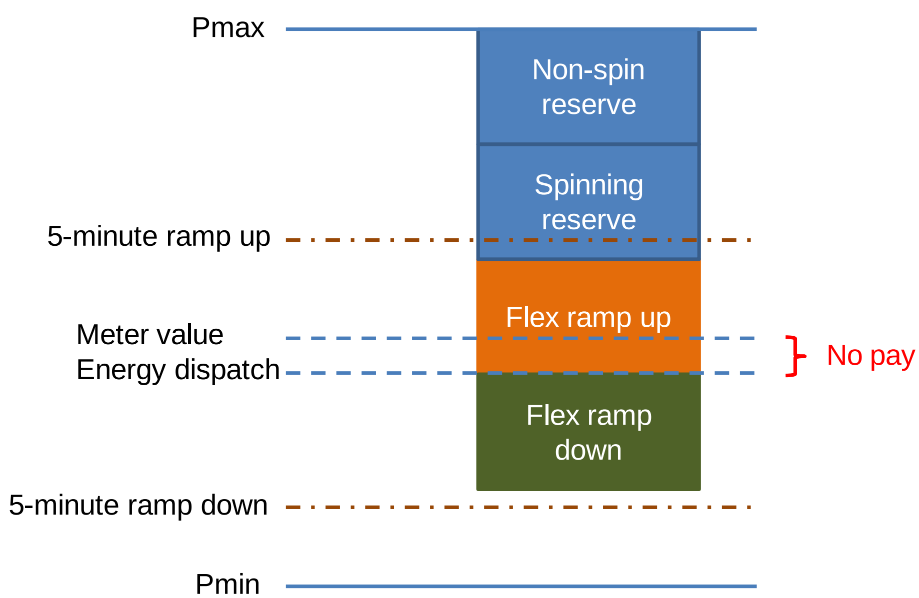

FIGURE 12: A RESOURCE WITH UNAVAILABLE CAPABILITY NO PAY

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

3. FLEX RAMP EXAMPLES

In this section, we will discuss several examples. The examples in Section 3.1 will demonstrate the properties of the flexible ramping product in RTD market. The example in Section 3.2 will demonstrate how flex ramp is settled.

3.1 PROPERTIES OF FLEX RAMP

In this section, we use a 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 flexible ramping, and ignore ancillary services.

3.1.1 UPWARD FLEX RAMP

Assume there are two 500 MW online resources in the system that could provide flexible ramping. The bids and parameters of the two generators are listed in Table 7. 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 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 7: 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

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

TABLE 8: SINGLE-INTERVAL RTD DISPATCH WITHOUT UPWARD FLEX RAMP

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

TABLE 9: SINGLE-INTERVAL RTD DISPATCH WITH UPWARD FLEX RAMP

	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 10: LOOK-AHEAD RTD DISPATCH WITHOUT UPWARD FLEX RAMP

	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 11: LOOK-AHEAD RTD DISPATCH WITH FLEX RAMP UP REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED UPWARD LOAD RAMP

The solution for scenario 1 is listed in Table 8. In scenario 1, load is met by the most economic resource G1, and G1 sets the LMP at $25.

The solution for scenario 2 is listed in Table 9. In scenario 2, in order to meet 170 MW upward flex ramp, G1 needs to be dispatched down in order to make room for upward flex ramp. As a result, G1 do not have extra capacity to meet extra load, and LMP is set by G2 at $30. Note the upward flex ramp requirement causes the LMP to increase compared with scenario 1. The upward flex ramp price FRUP is set by G1's energy opportunity cost $30 – $25= $5.

The solution for scenario 3 is listed in Table 10. In scenario 3, there is not flex ramp requirement. However, the look-ahead optimization projects a 170 MW of upward load ramp from interval t to t+5, which equals the upward flex ramp 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 flex ramp requirement in interval t. The LMPs are different because there is an interaction between the energy price and flex ramp 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 flex ramp 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+5	Load = 589.99 MW	Load = 590.01 MW
G1	500	500

G2	89.99	90
LMP	$30/MWh	$1000/MWh

TABLE 12: POSSIBLE LOOK-AHEAD RTD DISPATCH WITHOUT FLEX RAMP IN INTERVAL T+5

In scenario 4, both flexible ramping and look-ahead are modeled in the optimization. In order to have uniquely determined prices, we set upward flex ramp requirement slightly higher than expected load ramp 170 MW. The results are listed in Table 11, 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.

3.1.2 DOWNWARD FLEX RAMP

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 13. 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 13: 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

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

TABLE 14: SINGLE-INTERVAL RTD DISPATCH WITHOUT DOWNWARD FLEX RAMP

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

TABLE 15: SINGLE-INTERVAL RTD DISPATCH WITH DOWNWARD FLEX RAMP

	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 16: LOOK-AHEAD RTD DISPATCH WITHOUT DOWNWARD FLEX RAMP

	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 17: LOOK-AHEAD RTD DISPATCH WITH FLEX RAMP DOWN REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED DOWNWARD LOAD RAMP

The solution for scenario 1 is listed in Table 14. 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.

The solution for scenario 2 is listed in Table 15. In scenario 2, in order to meet 170 MW downward flex ramp, G2 needs to be dispatched up in order to provide downward flex ramp. 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 flex ramp requirement causes the LMP to decrease compared with scenario 1. The downward flex ramp 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 flex ramp 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.

The solution for scenario 3 is listed in Table 16. In scenario 3, there is no flex ramp 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 flex ramp 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 flex ramp requirement in interval t. The LMPs are different because there is an interaction between the energy price and flex ramp 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 flex ramp 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.

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.
- Flex ramp can decompose the pure energy price and flex ramp 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 flex ramp even if net system demand could be predicted with high accuracy.

3.2 AN SETTLMENT EXAMPLE

Now let's see how flex ramp is settled in 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 ($/MWh)		IIE/UIE (MWh)		Settlement ($)		
Energy	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
RTD	302	500	25	36	–148/12	50/12	–308.33	150.00	–158.33
Meter	420	420	27.78	27.78	118/12	80/12	273.15	–185.19	87.96
Total									1866.88

TABLE 18: AN ENERGY SETTLEMENT EXAMPLE

The Instructed Imbalance Energy (IIE) is RTD energy – IFM energy. The Uninstructed Imbalance Energy (UIE) is metered energy – RTD energy. The UIE price is calculated as the weighted average price based on absolute IIE. For example, (25*148/12+36*50/12)/(148/12+50/12)=27.78. With the weights being the absolute IIE, the weighted average price is always between the two 5-minute interval RTD prices.

Flex ramp is settled in a way very similar to energy. Similar to IIE and UIE, the delta FRU is RTD FRU – IFM FRU, and the unavailable FRU is available FRU based on meter – RTD FRU.

G1	Schedule (MW)		Price ($/MWh)		Delta/unavailable FRU (MWh)		Settlement ($)		
Energy	7:00	7:05	7:00	7:05	7:00	7:05	7:00	7:05	Total
IFM	4.17	4.17	20	20			6.95	6.95	13.90
RTD	198	0	0	10	193.83/12	−4.17/12	0	−3.48	−3.48
Meter	80	80	0.21	0.21	−118/12	80/12	−2.07	1.40	−0.67
Total									9.76

TABLE 19: A FLEX RAMP SETTLEMENT EXAMPLE

4. OTHER DESIGN ELEMENTS

4.1 GRID MANAGEMENT CHARGES

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

4.2 FLEXIBLE RAMPING PRODUCT DATA RELEASE

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

5. PIRP DEC BIDDING

In stakeholder comments, many parties representing variable energy resources have argued that additional market changes should be made prior to implementing the flexible ramping product. The ISO has stated throughout this stakeholder initiative that it believes that VERs can be suppliers of the flexible ramping product in the downward direction. For example, in the off peak hours, Scheduling Coordinators with self-schedules may find it more economic to procure (via the FRP cost allocation) downward dispatch capacity from variable energy resources to honor the self-schedule fixed ramp. The revenues from providing the flexible ramping product can be used to offset costs incurred by variable energy resources. A key requirement for providing the flexible ramping down product is that the resource must submit an energy bid in the real-time market.

The Participating Intermittent Resources Program (PIRP) currently does not allow economic bids. In order to receive the PIRP benefit of monthly settlement netting of uninstructed imbalance energy, the resource must submit a real-time self-schedule at the ISO-provided hourly forecast level. Since a resource must have an energy bid to provide the flexible ramping down product, the ISO proposes to implement PIRP DEC bidding with the flexible ramping product. In addition, while the current bid floor of ($30.00)/MWh is insufficient to cover VERs negative marginal costs, the ISO Board of Governors has approved lowering the bid floor to ($150.00)/MWh and then to ($300.00)/MWh as part of the Renewable Integration Market and Product Review Phase 1 stakeholder initiative. The lower bid floor will be implemented with the Bid Cost Recovery (BCR) enhancements which will separate day-ahead and real-time BCR.

On an hourly basis, PIRP resources that wish to participate in the flexible ramping down product will provide the hourly PIRP schedule, DEC bid price, maximum MW to be curtailed from the PIRP schedule, ramp rate, and FRD bid price. In RTUC, the ISO will utilize the ISO forecasted 15 minute expected output, to assess the amount of downward dispatch headroom. A PIRP resource can be awarded flexible ramping down in RTD based upon the amount it can ramp down in 5 minutes, which is the same rule for any other resource providing FRP. The PIRP resource with a DEC bid can be dispatched economically in RTD below its 15 minute expected output and up to the maximum MW to be curtailed below its hourly schedule. If a resource receives a dispatch or is awarded flexible ramping down in an RTD interval, the 10 minute settlement interval will be removed from the monthly PIRP netting and will be settled as instructed energy, the same as any other supply resource. Any interval in which the PIRP resource is not dispatched down or awarded flexible ramping down, the resource will remain in the PIRP monthly net calculation for any deviations.

The following table illustrates the use of PIRP DEC bidding.

Not dispatched or awarded FRD beyond maximum curtailment

Max Curtailment (MW)	60.0
Ramp Rate (MW/Min)	6
Bid Price	$ (100)
Maximum FRD Capacity (MW)	30.0

	Hour 1					
PIRP RT Self-Schedule (MW)	120.0				120.0	MWh
	RTUC 1	RTUC 2	RTUC 3	RTUC 4		
RTUC Expected Output (MW)	50.0	80.0	120.0	150.0	100.0	MWh

	RTD 1	RTD 2	RTD 3	RTD 4	RTD 5	RTD 6	RTD 7	RTD 8	RTD 9	RTD 10	RTD 11	RTD 12		
RTD Expected Output (MW)	50.0	50.0	50.0	80.0	80.0	80.0	120.0	120.0	120.0	150.0	150.0	150.0		
Bid Price	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)	$ (100)		
LMP	$ (150)	$ (50)	$ (50)	$ (50)	$ (150)	$ (90)	$ (150)	$ (90)	$ (150)	$ (150)	$ (50)	$ (75)		
FRD Award (MW)	0.0	0.0	0.0	20.0	0.0	20.0	30.0	30.0	30.0	30.0	30.0	30.0	18.3	MWh
Dispatch (MW)	120.0	120.0	120.0	120.0	60.0	120.0	90.0	120.0	90.0	120.0	120.0	120.0	110.0	MWh

Settlement	Int 1	Int 2	Int 3	Int 4	Int 5	Int 6		
Meter (MWh)	7.0	15.0	20.0	15.0	21.0	36.3	114.3	MWh
IIE (MWh)	20.0	20.0	15.0	17.5	17.5	20.0	110.0	MWh
UIE (MWh)	-13.0	-5.0	5.0	-2.5	3.5	16.3	4.3	MWh
PIRP Monthly Netting Settlement	Yes	No	No	No	No	No		

FRD Award Capacity Limited

Resource is dispatched or awarded FRD UIE not eligible for monthly netting

TABLE 20 – PIRP DEC BIDDING EXAMPLE

A Variable Energy Resource that is not in PIRP but is actually able to respond to dispatch instruction in upward and downward direction may participate in the flexible ramping products similar other resources so long as they have submitted an energy bid for real-time dispatch.

6. 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 board meeting. The ISO will finalize the cost allocation guiding principles after completion of this initiative. The ISO will then commence a stakeholder initiative to review other cost allocations to ensure consistency with the guiding principles. Based upon stakeholder comments to the draft final proposal and at the Board of Governors meeting, the ISO has renamed guiding principle three to better reflect the intent of the guiding principle. 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.

Based upon comments at the August 16 stakeholder meeting and September 18 technical workshop, the ISO has made the following changes:

- Self-schedules of internal generation are included in the supply category only.
- The supply category will be allocated based upon gross 10 minute deviations plus changes in hourly real-time self-schedules.

- Allow variable energy resources to elect to submit their own 15 minute forecast, the ISO 15 minute forecast, or the hourly self-schedule.

6.1 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. Movement for load is defined as changes in observed load every ten minutes. Movement for supply is defined as changes in uninstructed imbalance energy and change in internal self-schedules every ten minutes. Movement for static intertie ramps is calculated based upon the change in MWhs deemed delivered every 10 minutes. 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. This is more aligned with the Causation cost allocation guiding principle than the previous proposal of gross deviations for the initial cost split.

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 system procurement target and a lower relative initial allocation to one 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 both the day-ahead and real-time market. The flexible ramping product costs are represented by the blue (Up) and green (Down) pies in Figure 2.

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

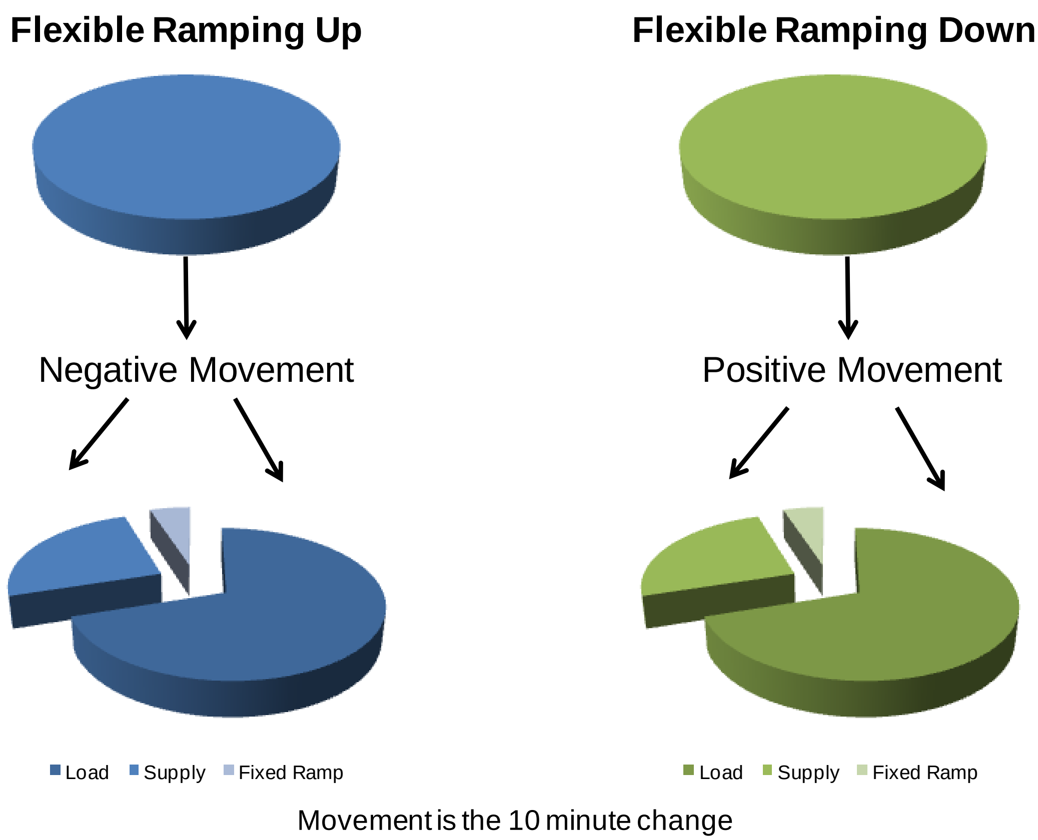

FIGURE 13 - FLEXIBLE RAMPING PRODUCT COST ALLOCATION

The ISO has analyzed data from January 1, 2012 through March 31, 2012. The following two graphs show the initial cost allocation to each of the categories by percentage on an hourly basis. The charts below include internal day-ahead self-schedule energy. The ISO did not include adjustments to internal self-schedule energy made in the real-time market in the supply category data as this could potentially double count PIRP resources and real-time self-schedules averaged fewer than 2% of day-ahead self-schedule energy. Fixed ramp includes movement from static intertie schedules only The ISO honors the hourly ramps through penalty prices regardless of whether real-time system conditions are or are not aligned with the fixed ramps, which requires internal generation to be available for RTD dispatch.

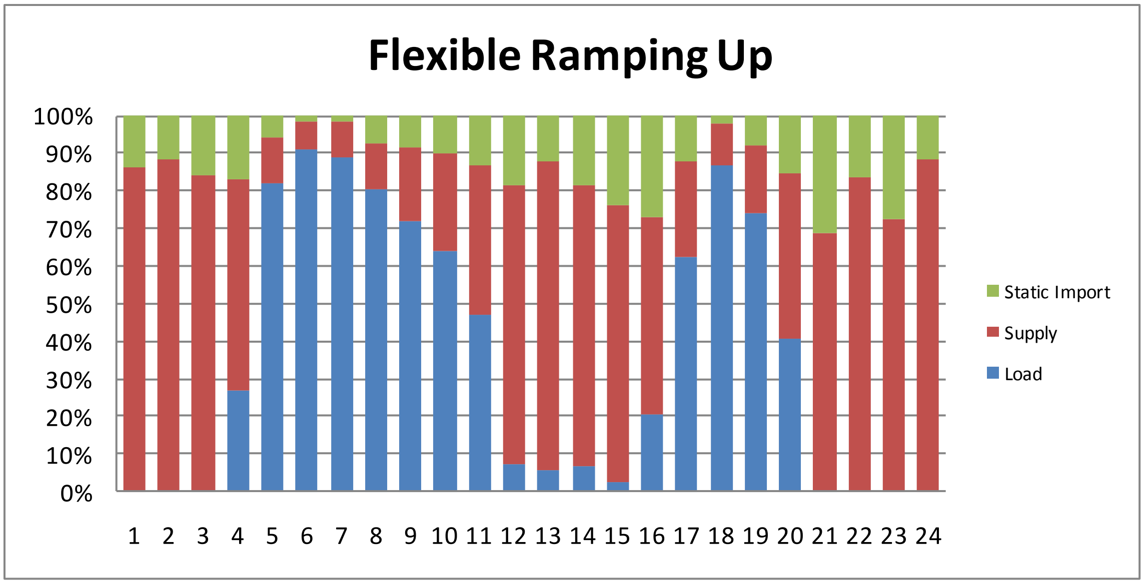

FIGURE 14 - % FRU MOVEMENT BY CATEGORY

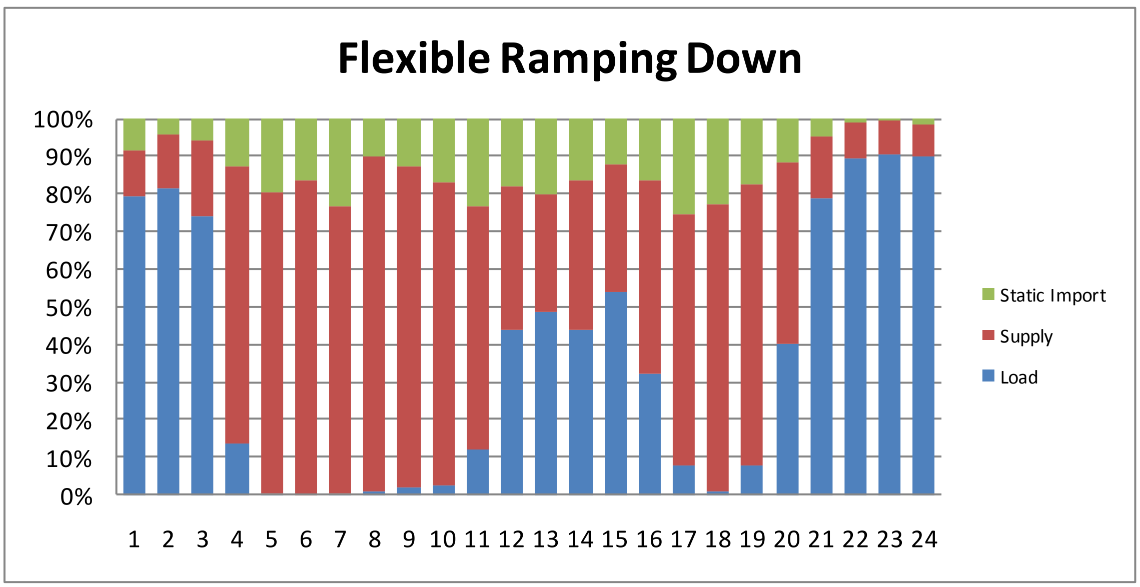

FIGURE 15 - % FRD MOVEMENT BY CATEGORY

The following two figures estimate the 5 minute average deviations in each hour by category.

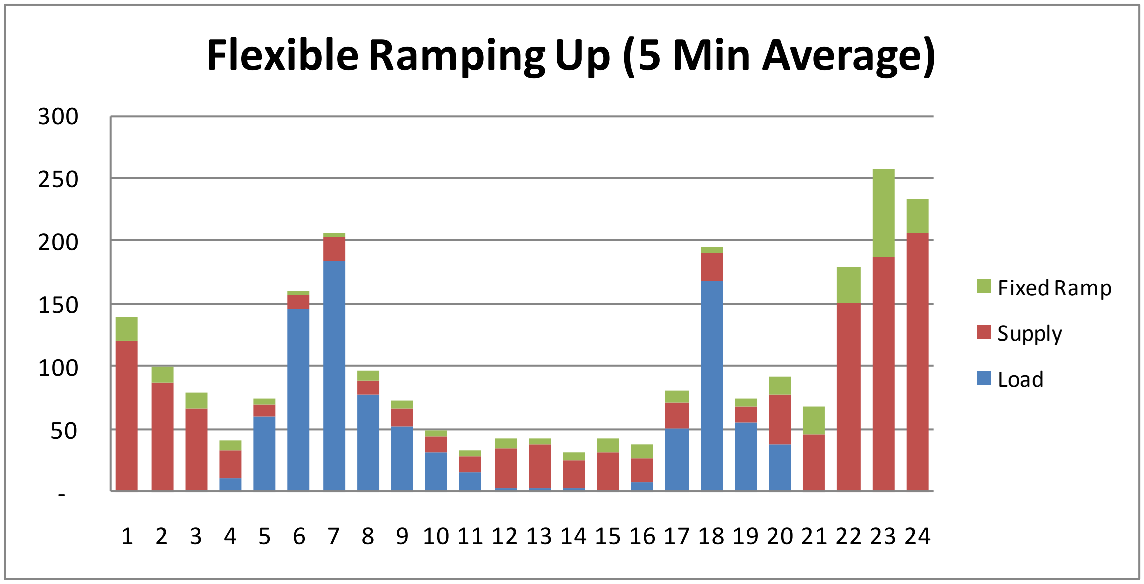

FIGURE 16 - AVERAGE FRU USING ESTIMATED 5 MINUTE MOVEMENT

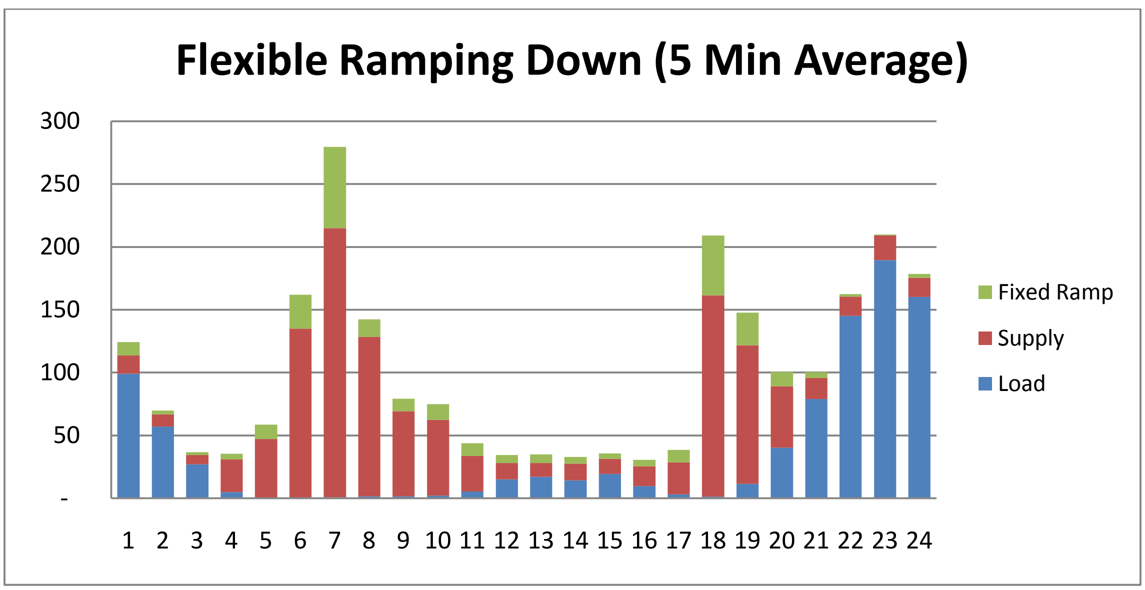

FIGURE 17 - AVERAGE FRD USING ESTIMATED 5 MINUTE MOVEMENT

The ISO has also posted a spreadsheet on the website which includes the movement and deviation data used to calculate Figures 3-6.

6.2 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 10 minute granularly based upon actual observations. Ten minute granularity aligns with the metering of supply resources.

The ISO previously proposed to use the ISO RTPD demand forecast as the hourly profile to calculate the baseline for measuring Load deviations. However, the use of observed load movement removes any biasing that was embedded within the RTPD forecast which provides a better measure for the initial allocation.

Some argued that 10 minute movement should be measured as changes in deviations to day-ahead schedule of Load. Given the hourly metering of Load, this approach does not align with actual system conditions requiring the flexible ramping product. As the table below shows, Load perfectly met the hourly day-ahead schedule. According to the argument, no need for the flexible ramping product up existed and Load should not be allocation any costs. However, the ISO needed to have dispatchable resources available to meet the linear ramp across the hour. The ISO has posted this table on the initiative website.

	Int 1	Int 2	Int 3	Int 4	Int 5	Int 6	
Actual Load	100	128	163	208	265	338	1200
Meter (MWh)	200	200	200	200	200	200	1200
DA Schedule (MWh)	200	200	200	200	200	200	1200
UIE	0	0	0	0	0	0	0
10 Minute Dispatch Change	0	28	35	45	57	73	
Delta UIE	0	0	0	0	0	0	

TABLE 21 – IMPACT OF HOURLY METERING ON ACCURATELY REFLECTING FRU REQUIREMENTS

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 10 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 10 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.

6.3 BILLING DETERMINANT OF SUPPLY CATEGORY

The supply category will be allocated based upon the 10 minute uninstructed deviations plus changes in hourly real-time self schedules. Thus for conventional resources, uninstructed deviations will net against self-schedule changes For variable energy resources, uninstructed deviations will be measured based upon the 15 minute expected energy as discussed below. PIRP self-schedules will not be included in the hourly real-time self-schedule changes.

The following tables provide examples for changes in real-time self-schedules.

HE 01 RT SS (MW)	100						
HE 02 RT SS (MW)	160						
				Hour Ending 2			
	INT 1	INT 2	INT 3	INT 4	INT 5	INT 6	Total
Uninstructed Imbalance Energy (MWh)	-5	-10	-15	0	5	10	
RT Self Schedule Hourly Change (MWh)	10	10	10	10	10	10	60
Net	5	0	-5	10	15	20	60
Flexible Ramping Up	0	0	5	0	0	0	5
Flexible Ramping Down	5	0	0	10	15	20	50

TABLE 22 – INCREASE IN REAL-TIME SELF-SCHEDULE

HE 01 RT SS (MW)	100						
HE 02 RT SS (MW)	40						
				Hour Ending 2			
	INT 1	INT 2	INT 3	INT 4	INT 5	INT 6	Total
Uninstructed Imbalance Energy (MWh)	-5	-10	-15	0	5	10	
RT Self Schedule Hourly Change (MWh)	-10	-10	-10	-10	-10	-10	-60
Net	-15	-20	-25	-10	-5	0	-60
Flexible Ramping Up	15	20	25	10	5	0	75
Flexible Ramping Down	0	0	0	0	0	0	0

TABLE 23 – DECREASE IN REAL-TIME SELF SCHEDULE

The settlement system does not currently support comparison with a previous settlement interval, using delta UIE is more complex than utilizing gross uninstructed deviations to allocate the supply category. While delta UIE is will be used for the initial allocation to the category, the ISO agrees with stakeholder comments that gross UIE provides greater clarity to incentivize behavior of resources. For example, if delta UIE was implementable, a resource that negatively deviated would first be allocated flexible ramping up costs and then when it returned to its instructed energy would be allocated flexible ramping down.

At the 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.

6.3.1 BASELINE TO MEASURE DEVIATIONS FOR CONVENTIONAL RESOURCES

The ISO has two types of uninstructed imbalance energy. Uninstructed imbalance energy 1 (UIE1) measures a resource's deviations up to its five minute dispatch over the 10 minute settlement interval. If a resource deviates greater than the 5 minute dispatch, the remaining deviation is measured as uninstructed imbalance energy 2 (UIE2). The flexible ramping products are procured for generation which has deviated from both its hourly schedule and ISO dispatch. If a resource deviates from the ISO dispatch, the subsequent RTD interval will dispatch other internal generation to make up the shortfall. In addition, if an internal 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 internal 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 based upon UIE1 and UIE2 changes.

6.3.2 BASELINE TO MEASURE DEVIATIONS FOR VARIABLE ENERGY RESOURCES

Currently the participating intermittent resource program (PIRP) requires resources to submit the ISO provided hourly forecast as a real-time self schedule in order to be eligible for monthly netting of imbalance energy. The ISO proposes to allow variable energy resources (both PIRP and non-PIRP) to select from (1) the ISO 15 minute forecast, (2) the resources 15 minute forecast, or (3) the hourly real-time self-schedule. The selection will be held in the Master File and used to measure the deviation for allocation of the supply category. The selection can be updated per the Master File business process which is approximately 10 business days for changes to become effective.. The real-time forecast will be used from 37.5 minutes prior to the "binding" RTPD interval. Every 15 minutes, the resource forecast will be updated and used as the baseline for the next "binding" RTPD interval. If a resource elects to provide its own 15 minute forecast of expected output and does not submit an updated forecast, the ISO will use its own 15 minute for the RTPD intervals that are missing

In order to be consistent with the Comparable Treatment guiding principle, the use of the real-time forecast is similar to conventional generation reporting of an outage. For conventional resources, once an outage is entered through SLIC, the imbalance energy is considered instructed imbalance energy even though it is settled at the real-time LMP.

Several stakeholders expressed concerns of potential gaming since there is no energy settlement impact of a resource's submitted expected energy output. For example, in periods where the cost of flexible ramping up is high, the resource could avoid the allocation by always ensuring that they have positive uninstructed imbalance energy. To address gaming concerns with allowing resources to submit their own 15 minute forecast of expected energy, the ISO will analyze the resource specific forecast every six months and provide this analysis to the Department of Market Monitoring. If a resource's submitted forecast systematically avoids the cost allocation, this behavior may be referred to FERC.

The ISO will be commencing a stakeholder initiative to address 15 minutes scheduling in compliance with the FERC Integration of Renewable Resources rule making. A potential outcome of this initiative is that 15 minute schedules become financially binding. If this occurs, the gaming concerns could be mitigated by the financial settlement of the expected energy.

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

6.3.3 THRESHOLD FOR ALLOCATION

Several stakeholders have commented that a threshold, similar to the uninstructed deviation penalty 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. This is consistent with the Management and Incentive Behavior cost allocation guiding principles.

The ISO proposes to allow a 3% threshold for allocation of the supply category. Unlike the uninstructed deviation penalty, 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 of 5 MWh divided by 6 for a given 10 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.

6.4 BILLING DETERMINANT OF FIXED RAMP CATEGORY

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

The ISO must honor the 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 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.

6.5 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 two-tiered 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 5 illustrated below the flexible ramping constraint has seen sufficient hourly differences.

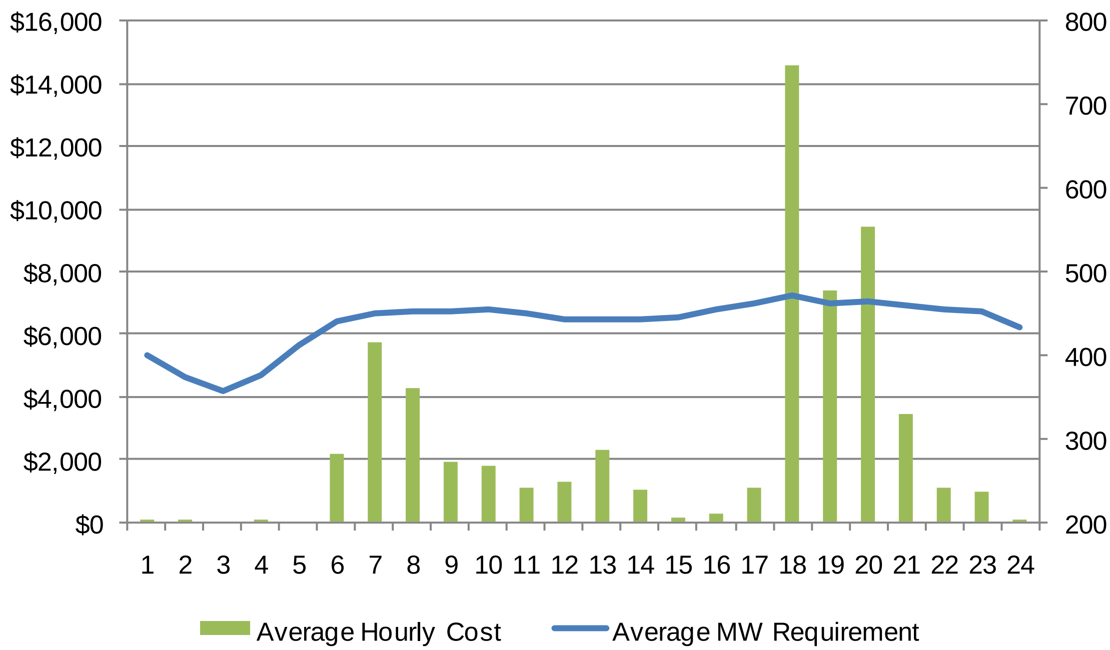

FIGURE 18 - HOURLY FLEXIBLE RAMPING CONSTRAINT COSTS JANUARY TO MARCH 2012

Utilizing the hourly cost of the flexible ramping constraint, the ISO can estimate the cost allocation by category for flexible ramping up. The ISO is currently not enforcing a constraint for flexible ramping down. The total cost of the flexible ramping constraint from January 1, 2012 through March 31, 2012 was $5.7 million. Using the percentage splits from Figure 5, the allocation to the load category would be $3.3 million (61%), the supply category would be $1.6 million (30%), and fixed ramps would be $0.5 million (10%).

6.6 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 resources deviations. At the end of the month, these hourly charges will be reversed, and the resource will be charge the monthly rate for each of its 10 minute deviations for each hour of the day.

6.7 ASSIGNMENT OF FLEXIBLE RAMPING COST ALLOCATION

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

PLAN FOR STAKEHOLDER ENGAGEMENT

Item	Date
Post 2nd Revised Draft Final Proposal	September 26, 2012
Technical Workshop	October 2, 2012
Stakeholder Comments Due	October 9, 2012
Board of Governors Meeting	TBD

NEXT STEPS

The ISO will hold a technical workshop on October 2, 2012. The ISO is seeking written comments by October 9, 2012. Stakeholder comments should be sent to FRP@caiso.com. The ISO will market notice an updated initiative schedule at a later date.

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.[10] 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,[11] 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.

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

[10] 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.

[11] 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[12].

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.

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