Flexible Ramping Products

Revised Draft Final Proposal

Lin Xu, Ph.D.

Market Analysis and Development

and

Donald Tretheway

Market and Infrastructure Policy

August 9, 2012

Revised Draft Final Proposal – Flexible Ramping Products

Table of Contents

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 position of units and the fleet of units in real-time dispatch (RTD) sometimes lack sufficient ramping capability and flexibility to handle the 5-minute to 5-minute system load and supply changes. The fleet of units in RTD is determined in the real-time unit commitment process (RTUC), also known as the real-time pre-dispatch (RTPD) process. Insufficient ramping capability sometimes manifests itself in triggering power balance violations, which means the there is no feasible system wide RTD schedule to maintain supply and demand power balance. In this case, the system has to rely on regulation services to resolve the issue in real delivery time after the imbalance has caused frequency deviation or area control error (ACE), which is undesirable outcome. If there is insufficient regulation service, the result of insufficient ramping capability may result in leaning on interconnection, which may affect the ability to meet required operational performance critieria. In addition, when power balance is violated, the RTD energy price is not priced by economic bids, but by administrative penalty prices, which may impact market efficiency in the long run.

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.

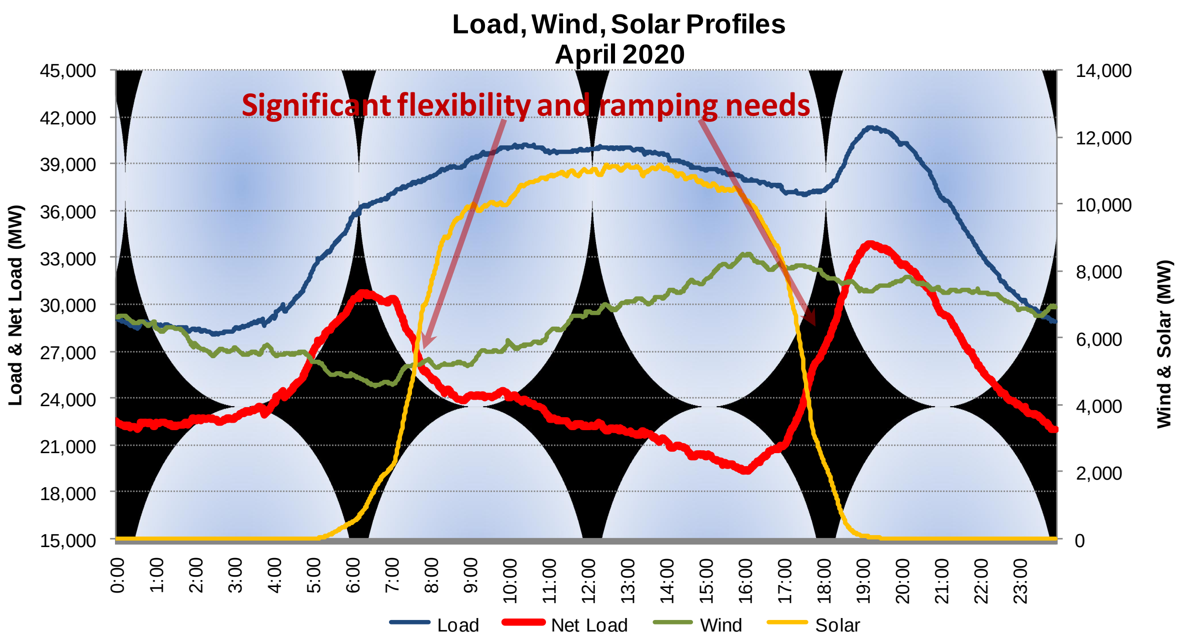


FIGURE 1: PROJECETED LOAD AND RENEWABLE PROFILES IN APRIL 2020[1]

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

---

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

[2] See CAISO Technical Bulletin "Flexible Ramping Constraint" for detailed discussion of the constraint, http://www.caiso.com/Documents/TechnicalBulletin-FlexibleRampingConstraint_UpdatedApr19_2011.pdf,

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.

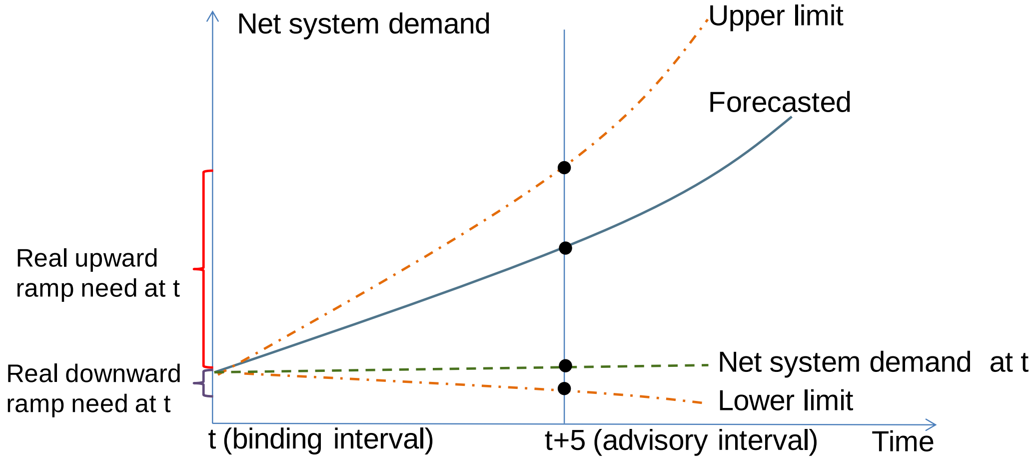
The flexible ramping product to be developed in this stakeholder process will help the system to maintain and use dispatchable flexibility in terms of ramping capability. The flexible ramping product is the 5-minute ramping capability commodity, which will be dispatched to meet 5-minute to 5-minute net 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 }

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. Therefore, the clear distinction between flexible ramping product and regulation services is that flexible ramping product takes care of ramping issue before the binding RTD dispatch, and regulation services takes care of ramping issue after the binding RTD dispatch.

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.

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



Real ramping need:
Potential net load change from t to t+5
(net system demand t+5 – net system demand t)

FIGURE 2: REAL RAMPING NEED

The major changes in the revised draft final proposal compared with the draft final proposal include:

1. changing ramping need from unexpected ramp to real interval to interval net system movement (Section 1)
2. flexible ramping requirement and demand curve aligned with real ramp definition (Section 2.3)
3. model ramping capability over the market clearing interval rather than over 5 minutes (Section 2.4)
4. allow unawarded regulation capacity to be used as flexible ramping (Section 2.4)
5. allow economic buyback of flexible ramping in real-time market (Section 2.5.2)
6. eliminate flexible ramping self provision (Section 2.1.2)
7. not factoring energy bid into flexible ramping bid cost
8. only model explicit conversion from day-ahead non-contingent spinning reserve award to upward flexible ramping in real-time, but do not model explicit conversion from flexible ramping to spinning reserve (Section 2.5.3)
9. PIRP dec biding (Section 5)
10. cost allocation aligned with real ramp definition (Section 6)

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 award flexible ramping capability to preserve it into real-time markets. 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 movement. Whether a portion of the net system demand changes can be predicted or not, the ramping capability is in need.

Dispatched in RTD on a regular basis Flexible ramping product is the 5-minute ramping capability continuously being dispatched in RTD to meet the net system movement. No such capability product exists in the ISO's current market. Regulation services are dispatched in real-time by Automatic Generation Control, not through economic bids. Operating reserves are 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 in RTUC and RTD. The purpose of modeling flexible ramping in RTUC is to help 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. It is more appropriate to bindingly procure flexible ramping capability in RTD than in RTUC 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

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

A resource can provide flexible ramping as long as it has an economic energy bid. It does not need to have a certified flexible ramping capability. 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 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 inadvertent 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.

However, an SC can bid zero or simply not bid for flexible ramping if it intends to self provide the product. Then the flexible ramping cost will be purely based on opportunity cost. The optimization can give awards to resources according to economic order of providing flexible ramping. If the SC is fully awarded flexible ramping, then it effectively hedges its cost allocation with the payment received. If the SC is not fully awarded flexible ramping (even with bid price $0/MWh), it implies the marginal price of flexible ramping must be $0/MWh, so there will be zero cost allocation. In either case, an SC can hedge its cost allocation effectively, so there is no need for an explicit flexible ramping self provision.

2.1.3 FLEXIBLE RAMPING MARKET POWER MITIGATION

The ISO believes that the bid cap, the implicit flexible ramping offer from economic energy offers, flexible ramping demand curve (discussed later), and the regulation participation (discussed later) should adequately address the concern of market power. Therefore, the ISO will not propose a more sophisticated market power mitigation.

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.

In the IFM, the flexible ramping products will be modeled in each hour. The RTUC and RTD are both multi-interval look-ahead optimization. The flexible ramping products will be modeled by ramping constraints in each interval of RTUC and RTD.[3] 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.[4] 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.

---

[3] 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.

[4] 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.

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

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 ramping capability over the market clearing interval rather than over 5 minutes[5].

Regulation service capacity can be used to meet flexible ramping requirement. However, regulation services procured to meet flexible ramping needs will be dispatched by RTD rather than by AGC. Regulation service dispatched by AGC is not available for dispatch by RTD, and leaves less flexibility in the RTD. Therefore, regulation service capacity used for ramping purpose does not substitute for flexible ramping product (if it is substitution, the award will regulation service dispatched by AGC). Instead, it will be awarded flexible ramping, and be dispatched in RTD. This is called regulation participating as flexible ramping. Note that the mileage payment for regulation will only apply to the regulation capacity on AGC, and not apply to the regulation capacity participating as flexible ramping.

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

The flexible ramping products will be priced at the marginal values of the requirements in the binding interval, which equal the corresponding shadow prices. Regulation service participating as flexible ramping will be paid the flexible ramping price, but not the regulation service price.

2.3 FLEXIBLE RAMPING REQUIREMENT AND DEMAND CURVE

The ISO will buy flexible ramping product in either direction up to the 95% of confidence level of between interval net system demand changes. In other words, the maximum requirement is the

---

[5] The ramping capability can be converted to the 5-minute ramping capability by dividing by an averaging factor AF (AF =: day-ahead 12, RTUC 4, and RTD 1). For example, if a resource has 600 MW ramping award over 60 minutes in day-ahead. This can be converted to 50 MW 5-minute ramping capability for 12 RTD intervals. The 50 MW 5-minute ramping award will be the basis to settle real-time flexible ramping award. If the resource is awarded 60 MW 5-minute ramping capability in RTD, the extra 10 MW will be paid the RTD flexible ramping price.

95% confident interval (from 2.5% percentile to 97.5% percentile). Such a confident interval for RTD is illustrated in Figure 3, which is based on real net system movement data from January to March 2012.

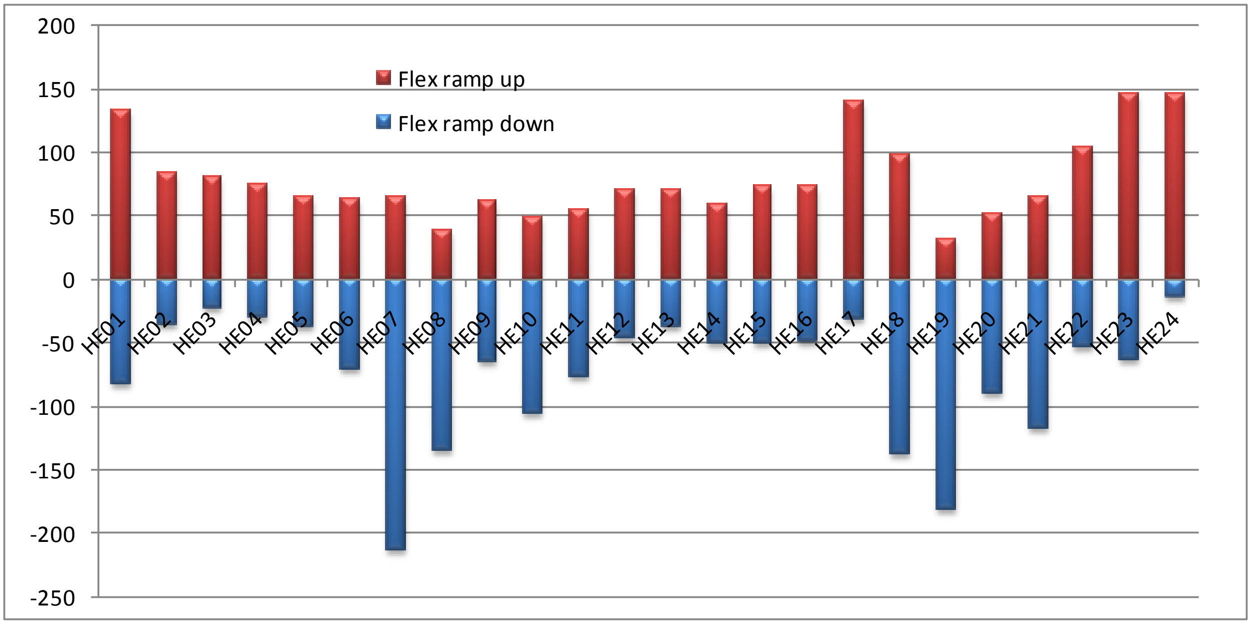


FIGURE 3: SAMPLE FLEXIBLE RAMPING MAXIMUM REQUIREMENT (95% CONFIDENCE INTERVAL)[6]

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.

From the minimum requirement to the maximum requirement, a demand curve specifies several price levels and corresponding flexible ramping demand quantities. The demand curve will drive the procurement amount according to flexible ramping supply price. Generally speaking, if the supply price is low, the procurement amount will be more. If the supply price is high, the procurement amount will be less. The 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 only consider the benefit of reducing power balance violation frequencies in RTD. Assume the historical distribution of the power balance violation (PBV) without the flexible ramping product[7] is available as listed in column

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

[7] 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.

1 of Table 1. Column 1 only lists the power balance violation in the direction of power shortage. Power shortage distribution is used to calculate upward flexible ramping demand curve. The downward flexible ramping demand curve can be calculated similarly with the power balance violation distribution in the direction of over generation. Column 2 of Table 2 is the distribution of the power balance violations with 100 MW of flexible ramping with the assumption that 100 MW of upward flexible ramping would resolve any power balance violations below 100 MW. With 100 MW of flexible ramping, any 100 MW to 200 MW power balance violation, that would occur without flexible ramping, will become 0 MW to 100 MW violation; any 200 to 300 MW power balance violation, that would occur without flexible ramping, will become 100 MW to 200 MW violation; and so on.

We also assume the power balance violation in each category is uniformly distributed, and the average power balance violation in each category is listed in Table 2.

0 MW flex ramp	100 MW flex ramp	200 MW flex ramp	300 MW flex ramp
0-100 MW PBV, 0.3%	0-100 MW PBV, 0.2%	0-100 MW PBV, 0.1%	0-100 MW PBV, 0%
100-200 MW PBV, 0.2%	100-200 MW PBV, 0.1%	100-200 MW PBV, 0%	100-200 MW PBV, 0%
200-300 MW PBV, 0.1%	200-300 MW PBV, 0%	200-300 MW PBV, 0%	200-300 MW PBV, 0%

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

0 MW flex ramp	100 MW flex ramp	200 MW flex ramp	300 MW flex ramp
average(0-100 MW PBV)= 50 MW	average(0-100 MW PBV)= 50 MW	average(0-100 MW PBV)= 50 MW	average(0-100 MW PBV)= 50 MW
average(100-200 MW PBV)= 150 MW	average(100-200 MW PBV)= 150 MW	average(100-200 MW PBV)= 150 MW	average(100-200 MW PBV)= 150 MW
average(200-300 MW PBV)= 250 MW	average(200-300 MW PBV)= 250 MW	average(200-300 MW PBV)= 250 MW	average(200-300 MW PBV)= 250 MW

TABLE 2: AVERAGE POWER BALANCE VIOLATION

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[8] as in Table 3.

Power balance violation	Penalty
0-100 MW	$1000/MWh
100-200 MW	$3000/MWh

[8] These penalty values are for illustration only. Currently, the under generation penalty in the market is $1000 for blow 350 MW violation and $6500 for above 350 MW violation. The ISO may need a separate process to increase the penalty function granularity to fulfill the flexible ramping need.

200-300 MW	$5000/MWh

TABLE 3: POWER BALANCE VIOLATION PENALTIES

Then we can calculate the value of flexible ramping as follows. The system cost without flexible ramping and with 100 MW of flexible ramping is listed in Table 4. Therefore, the value of the first 100 MW of flex ramp is

(cost0 – cost100)/100 = (2300 – 550)/100 = $17.5/MWh.

Similarly, the value of the second 100 MW of flex ramp is

(cost100 – cost200)/100 = (550 – 50)/100 = $5/MWh.

The value of the third 100 MW of flex ramp is

(cost200 – cost300)/100 = (50 – 0)/100 = $0.5/MWh.

Cost0 = system penalty cost associated with 0 MW flex ramp =	Cost100 = system penalty cost associated with 100 MW flex ramp =
Average(0-100 MW PBV)*0.3%*1000+ average(100-200 MW PBV)*0.2%*3000+ average(200-300 MW PBV)*0.1%*5000	Average(0-100 MW PBV)*0.2%*1000+ average(100-200 MW PBV)*0.1%*3000+ average(200-300 MW PBV)*0%*5000
= 50*0.3%*1000+ 150*0.2%*3000+ 250*0.1%*5000	= 50*0.2%*1000+ 150*0.1%*3000+ 250*0%*5000
= $2300/h	= $550/h

TABLE 4: SYSTEM COST COMPARISON OF NO FLEX RAMP AND 100 MW FLEX RAMP

Cost200 = system penalty cost associated with 200 MW flex ramp =	Cost300 = system penalty cost associated with 300 MW flex ramp =
Average(0-100 MW PBV)*0.1%*1000+ average(100-200 MW PBV)*0%*3000+ average(200-300 MW PBV)*0%*5000	Average(0-100 MW PBV)*0%*1000+ average(100-200 MW PBV)*0%*3000+ average(200-300 MW PBV)*0%*5000
= 50*0.1%*1000+ 150*0%*3000+ 250*0%*5000	= 50*0%*1000+ 150*0.1%*3000+ 250*0%*5000
= $50/h	= $0/h

TABLE 5: SYSTEM COST COMPARISON OF 200 MW FLEX RAMP AND 300 MW FLEX RAMP

The complete demand curve is as follows

MW	Price
0-100 MW	$17.5/MWh
100-200 MW	$5/MWh
200-300 MW	$0.5/MWh

TABLE 6: UPWARD FLEXIBLE RAMPING DEMAND CURVE

This method only relies on the following inputs:

- 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 need to be assigned based on the risk of lost load or over gen. This method provides a simple and transparent way to construct the demand curve for flex ramp.

A complete flexible ramping requirement curve 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.

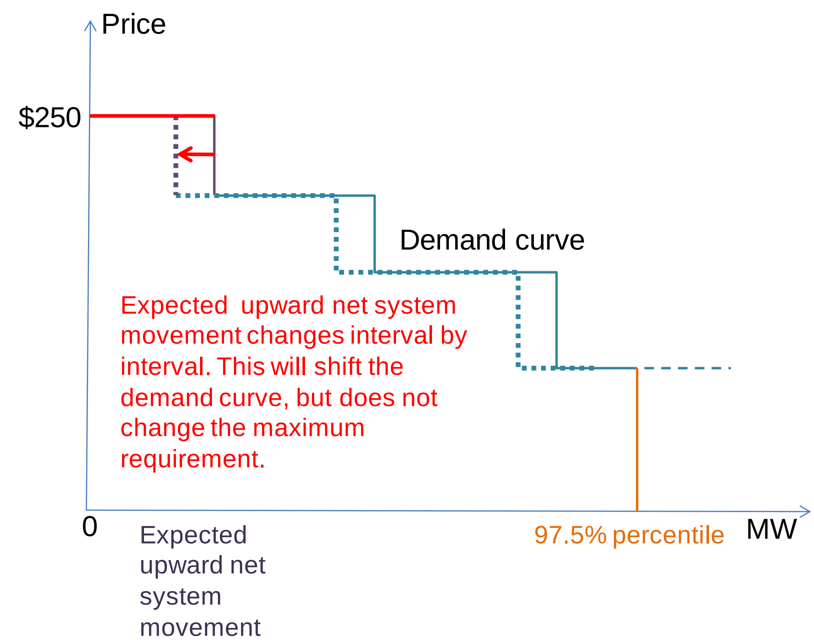


FIGURE 4: UPWARD FLEXIBLE RAMPING REQUIREMENT CURVE WITH UPWARD EXPECTED NET SYSTEM MOVEMENT)

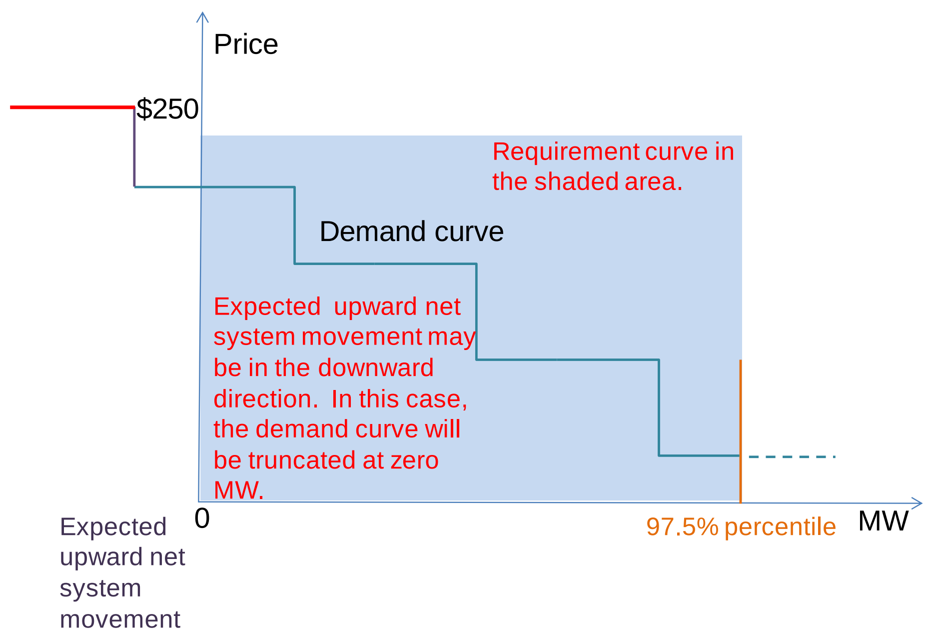


FIGURE 5: UPWARD FLEXIBLE RAMPING REQUIREMENT CURVE WITH DOWNWARD EXPECTED NET SYSTEM MOVEMENT

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 buy fewer 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.

In day-ahead and RTUC, the market clearing interval is not 5-minute. In this case, the procurement curve will be scaled accordingly by the averaging factor AF (AF =: day-ahead 12, RTUC 4, and RTD 1).

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.

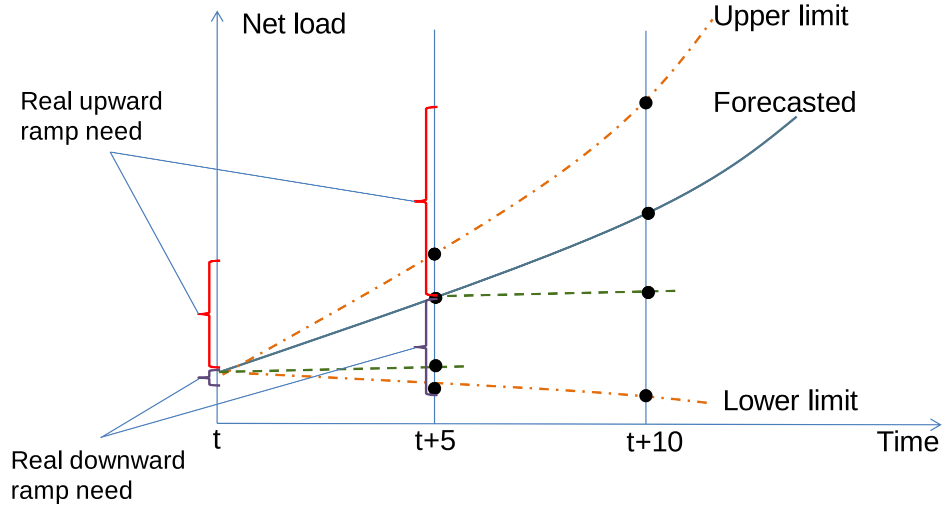


FIGURE 6: REAL RAMP NEED IN LOOK-AHEAD OPTIMIZATION

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. It is important to note that Reliability schedules for physical supply resources are greater than or equal to the corresponding Energy schedules so that the latter are feasible for the forecasted real-time conditions.

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 ECONOMIC BUYBACK IN RTD

Similar to energy schedule, day-ahead flexible ramping award should be allowed to be economically bought back in RTD. A resource that has an economic real-time flexible ramping offer and energy offer may get cleared differently from the day-ahead schedule. The difference between the RTD flexible ramping award and the day-ahead flexible ramping award will be paid the RTD flexible ramping price.

If day-ahead flexible ramping award is not allowed to be bought back in RTD, the resources with day-ahead flexible ramping award may strategically change the real-time energy offer to take advantage of the potential energy dispatch when the flexible ramping capability is deployed. Even if the resource's energy bid is uneconomic, and the flexible ramping capability is never deployed in real-time, the resource still keeps its day-ahead flexible ramping payment. However, in this case, the market has paid for some useless capacity.

In addition, allow 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.

2.5.3 CONVERSION OF DAY-AHEAD AWARDS IN RTUC

RTUC models flexible ramping in the optimization, but does not have binding settlement for flexible ramping capacity. The flexible ramping capability is referred as headroom. Settling flexible ramping headroom in RTUC may cause false opportunity cost payments, because the flexible ramping headroom is evaluated based on advisory energy schedules. While a resource by not be "awarded" an energy schedule in RTUC this does not prevent the resource from energy dispatch opportunities in RTD. That is why the ISO propose to settle flexible ramping award in RTD instead.

The day-ahead non-contingent spinning reserve awards or non-contingent non-spin reserve awards that are online in RTUC may be fully or partially converted to upward flexible ramping if the resources have economic energy bids in real-time market. The day-ahead non-contingent reserve awards are from resources who flag them as non-contingent meaning that they are willing to be dispatched for energy rather than be kept as operating reserve if system condition permits. Therefore, allowing them to be converted to flexible ramping product and then potentially be dispatched for energy is consistent with their intention. The potential conversions are summarized in Figure 7.

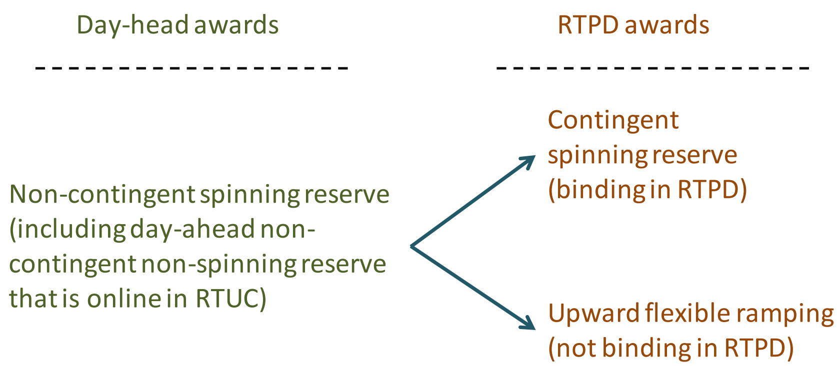


FIGURE 7: CONVERSIONS BETWEEN NON-CONTINGENT RESERVES AND UPWARD FLEXIBLE RAMPING PRODUCT IN RTUC

These conversions will increase the dispatch flexibility and market efficiency by allowing flexible resources to be used in the most valuable way. The conversion can only take place in RTUC, and only applies to day-ahead awards. Basically, the conversion design allows RTUC to make a second decision about the capacity awarded in IFM consistent with the resource's bidding strategy.

Conversion is different from the ancillary service substitution where regulation-up can substitute spinning reserve, and spinning reserve can substitute non-spinning reserve. Substitution happens in the direction from higher value product to a lower value product. Conversion is just the opposite, and will only happen in the direction of from lower value to higher value. Non-contingent spinning reserve can be converted to upward flexible ramping product only when the marginal price of upward flexible ramping is higher than or equal to the marginal price of spinning reserve in RTUC. This can be proved by contradiction. Assume the marginal price of spinning reserve is higher than the upward flexible ramping product, and at least one resource's non-contingent spinning reserve is converted to upward flexible ramping product. In this case, if the conversion is reduced by 1 MW, then the change to the objective function value is equal to the marginal price of upward flexible ramping product minus the marginal price of spinning reserve, which is negative by assumption. This means the objective function value can be improved (reduced) by reversing the conversion, and thus contradicts the optimality of the conversion. Therefore, the conversion should not have taken place.

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

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

The flexible ramping being converted from day-ahead spinning reserve, $FRU_{i,t}^{CONV}$, will be used to meet the upward flexible ramping requirement in RTUC. Note that the total upward flexible ramping headroom in RTUC still needs to satisfy the 5-minute ramping capability limit.

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

Conversion is a nice feature to have in the market. However, the ISO is still evaluating implementation complexity again its benefit. With regulation service participating as flexible ramping, the marginal benefit of the conversion may be limited. If the implementation complexity over weights the benefit, the conversion feature may be disallowed.

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.

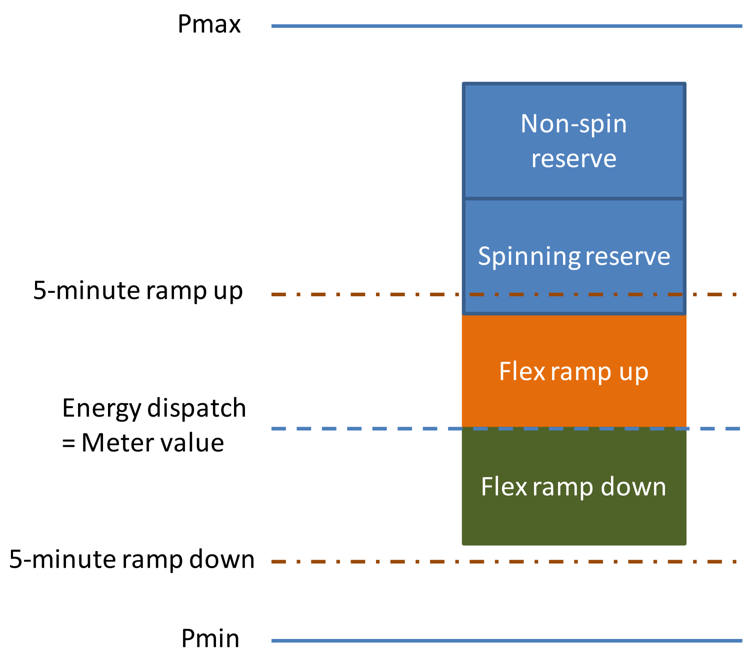


FIGURE 8: A RESOURCE WITH NO FLEXIBLE CAPCITY PAYMENT RECISSIONS

- **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.

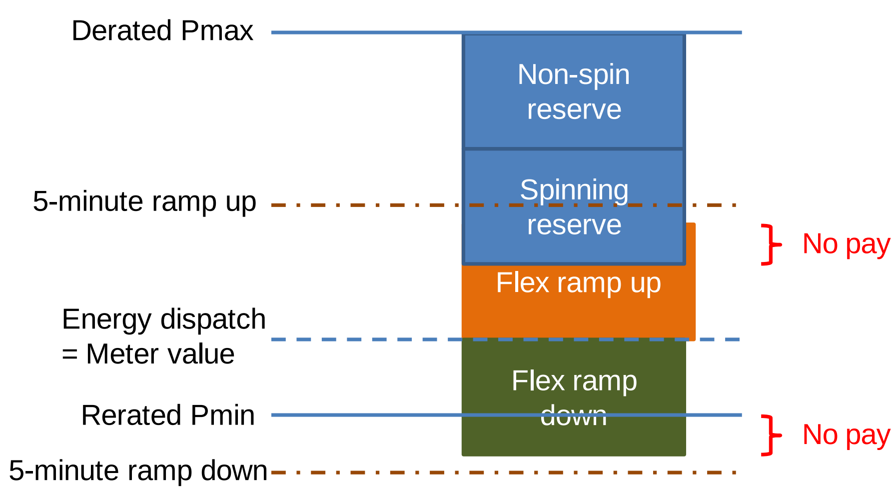


FIGURE 9: A RESOURCE WITH UNAVAILABLE FLEXIBLE RAMPING CAPABILITY NO PAY

- **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.

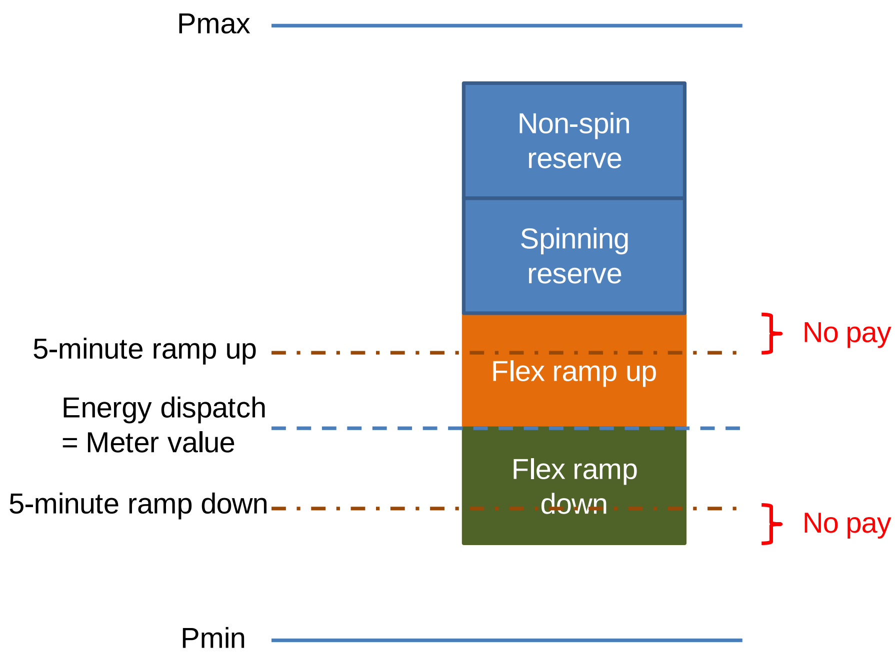


FIGURE 10: A RESOURCE WITH RAMP-LIMITED NO PAY

- **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.

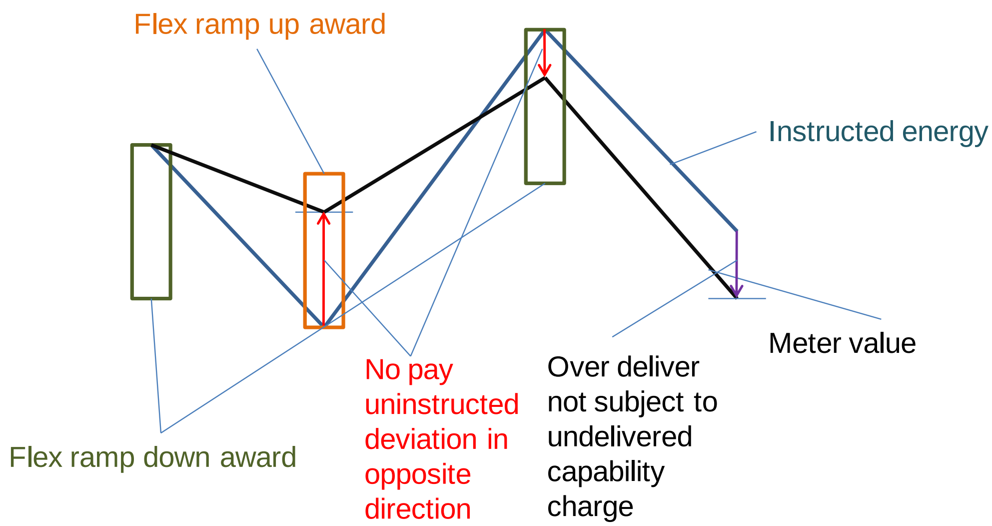


FIGURE 11: UNDELIVERED CAPABILITY NO PAY

- **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.

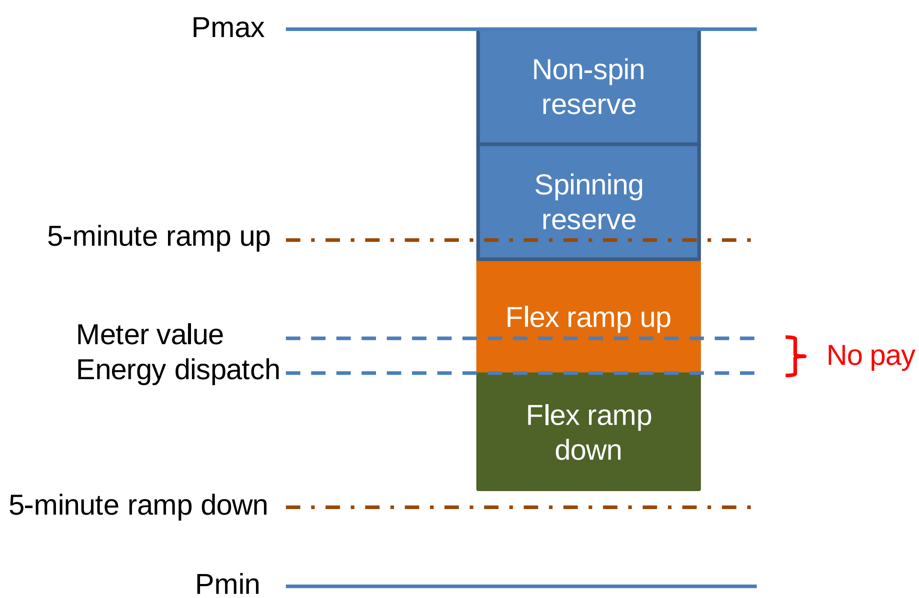


FIGURE 12: A RESOURCE WITH UNAVAILABLE CAPABILITY NO PAY

- **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. RTD EXAMPLES

In this section, we use a RTD example to demonstrate the properties and benefits of flexible ramping under the following assumptions

- flex ramp bid cost is zero
- net system movement is accurately predicted.

Assume there are two 500 MW online resources in the system that could provide flexible ramping. The bids and parameters of the three generators are listed in Table 7. G1 and G2 are fast resources with 100 MW/minute ramp rate, and G2 is a slow resource with 10 MW/minute ramp rate. G1 is more economic in energy than G2. They both have zero cost for providing flexible ramping. For simplicity, we only consider the interaction between energy and flexible ramping, and ignore ancillary services.

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

TABLE 7: RESOURCE BIDS, INITIAL CONDITION AND OPERATIONAL PARAMETERS

We will consider four scenarios:

- scenario 1: single interval RTD optimization without flexible ramping.
  - [Load at t] = 420 MW
- scenario 2: single interval RTD optimization with 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 flexible ramping
  - [Load at t] = 420 MW
  - [Load at t+5] = 590 MW
- scenario 4: two-interval RTD optimization with flexible ramping
  - [Load at t] = 420 MW
  - [Load at t+5] = 590 MW
  - [Upward flexible ramping requirement at t] = 170.001 MW
  - [Downward flexible ramping requirement at t] = 0 MW

	Interval t (LMP=$30, FRUP=$5)		
gen	Energy	Flex-ramp up	Flex-ramp down
G1	420		
G2	0		

TABLE 8: SINGLE-INTERVAL RTD DISPATCH WITHOUT 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 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 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 REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED LOAD RAMP

	Interval t (LMP=$25, FRUP=$0)			Interval t+5 (LMP=$35)		
gen	Energy	Flex-ramp up	Flex-ramp down	Energy	Flex-ramp up	Flex-ramp down
G1	380	120		500		
G2	40	50		90		

TABLE 12: LOOK-AHEAD RTD DISPATCH WITH FLEX RAMP REQUIREMENT SLIGHTLY LOWER THAN EXPECTED 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 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 LMP. 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, but why the LMPs are different. 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. More generally, $LMP^{S3} = LMP^{S2} – FRUP^{S2} + FRDP^{S2}$. 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 will suppress the energy price; when net system demand is decreasing, which creates more downward ramp need, the look-ahead optimization will inflate the energy price.

This effect may make resources be dispatched inconsistently with their offers. 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 13: 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. Again, to produce uniquely determined prices, we will consider two cases: upward flex ramp requirement is slightly higher than expected load ramp 170 MW, upward flex ramp requirement is slightly higher than expected load ramp 170 MW. The results are listed in Table 11 and Table 12. If the flexible ramping requirement is slightly higher than the expected load ramp, the solution converges to scenario 2. If the flexible ramping requirement is slightly lower than the expected load ramp, the solution converges to scenario 3. In reality, because of unpredicted deviation always exist, generally speaking, the flexible ramping requirement should be higher than the expected load ramp, so we expect to see the separate energy price and flex ramp price as in scenario 2 more often.

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, 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 will also result in less bid cost recovery because the energy price will be more consistent with the energy offer. These are advantages of flex ramp even if net system demand could be predicted with high accuracy.

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 anenergy 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, 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 same 15 minute expected output used for the baseline to allocate the flexible ramping product, 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 with 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 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, the resource will remain in the PIRP monthly net calculation for any deviations.

The following table illustrates the use of PIRP DEC bidding. The spreadsheet has been posted on the ISO initiative website.

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)		
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	Yes	No	No	No	Yes		

TABLE 14 – PIRP DEC BIDDING EXAMPLE

A VER resource that is not in PIRP but is actually able to respond to dispatch instruction in upward and downward direction may participate in flexible ramp 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 second technical workshop, the ISO has made the following changes:

- Included real-time self schedules data in the fixed ramp category;
- For the supply category, the deviation threshold for a given settlement interval is the minimum of 3% of instructed energy or 5MWh divided by 6;
- Further clarification to previous design elements.

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 generation is defined as changes in uninstructed imbalance energy every ten minutes. Movement for static intertie ramps and internal self-schedules 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.

The expectation of potential movement across all market participants results in the procurement of the flexible ramping product. When flexible ramping products are procured at the system level, the total system variability and uncertainty that may be realized as movement in RTD is the driver of the procurement target. There may be instances where on average two market participants offset each other's movement which decreases the overall system requirement. This offsetting impact decreases the quantity of the flexible ramping product the ISO must procure and is reflected in a lower system procurement target 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 the 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 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 variability and uncertainty that is observed as negative movement. The downward flexible ramping product is procured to address variability and uncertainty that is observed as positive movement.

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.

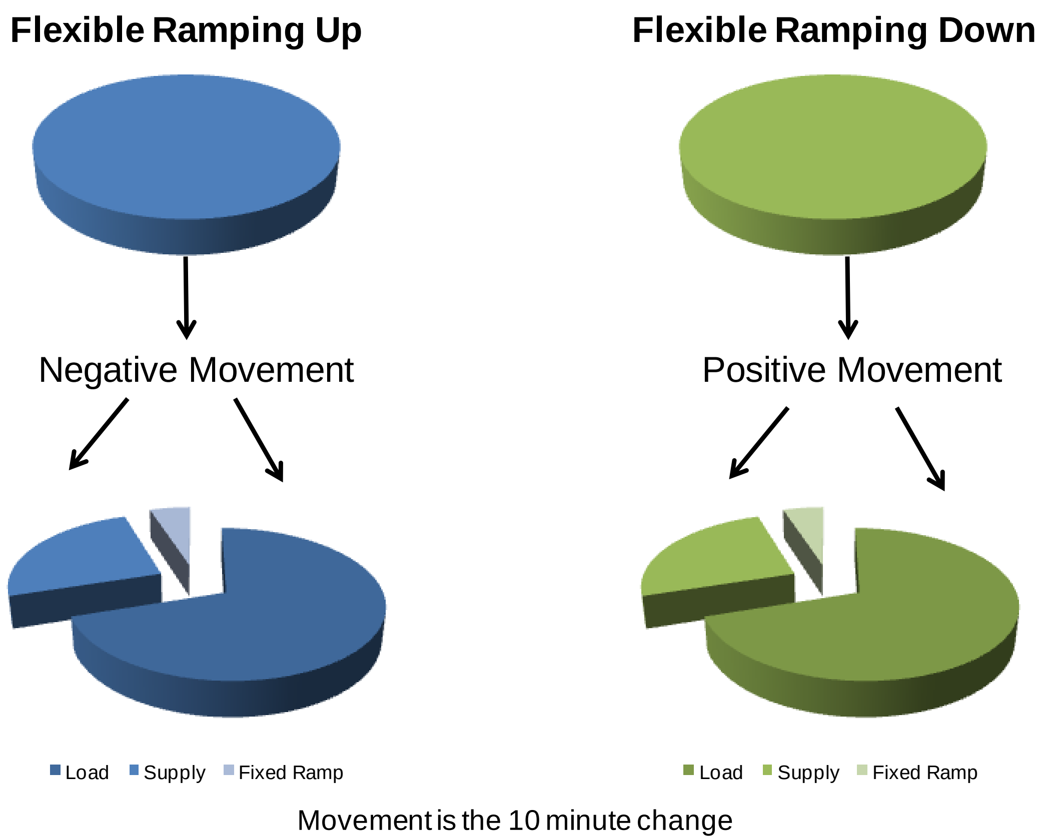


FIGURE 13 - FLEXIBLE RAMPING PRODUCT COST ALLOCATION

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 real-time self-schedule energy in the 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 resources that do not have and real-time economic bid which would make the resource available for real-time dispatch. As a result, the ISO honors the self-schedule ramps through penalty prices regardless of whether real-time system conditions are or are not aligned with the fixed ramps. If a resource self-schedules in the day-ahead market, i.e. is a price taker, but then submits real-time economic bids in the real-time market the resource is included in the supply category.

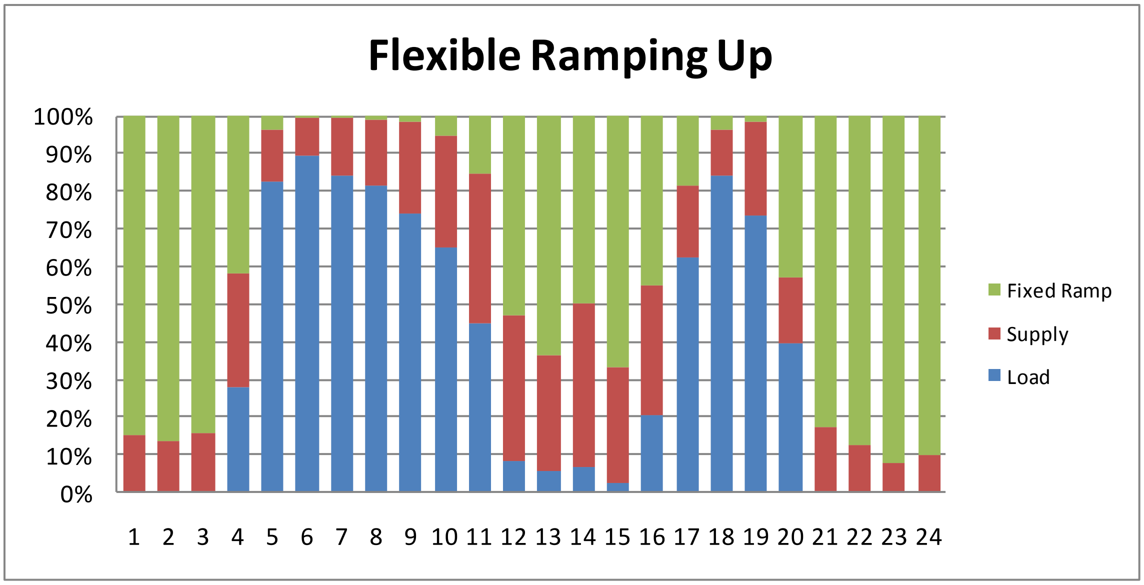


FIGURE 14 - % FRU MOVEMENT BY CATEGORY

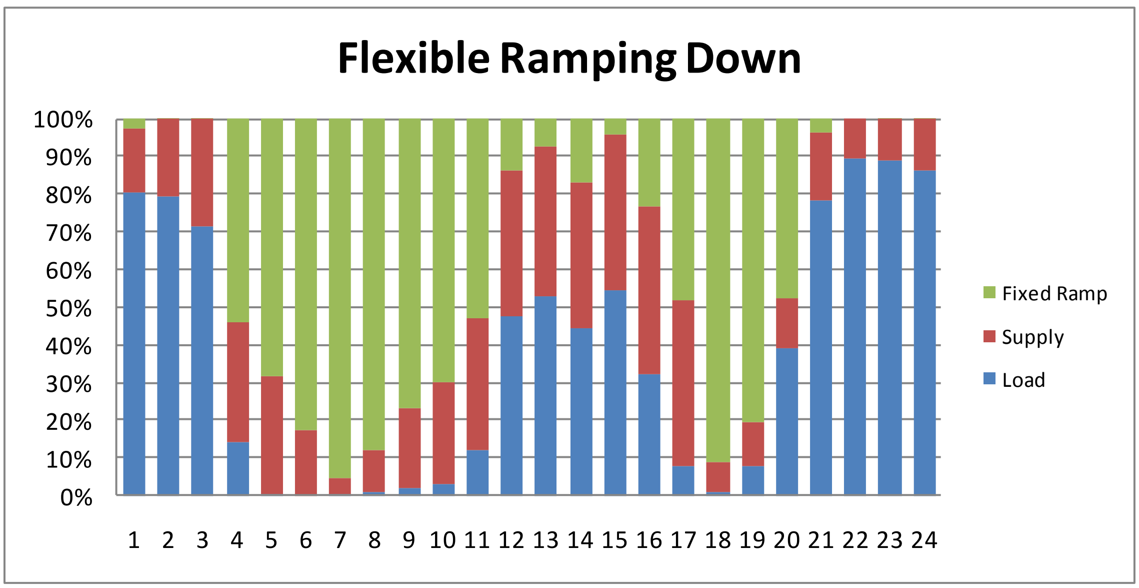


FIGURE 15 - % FRD MOVEMENT BY CATEGORY

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

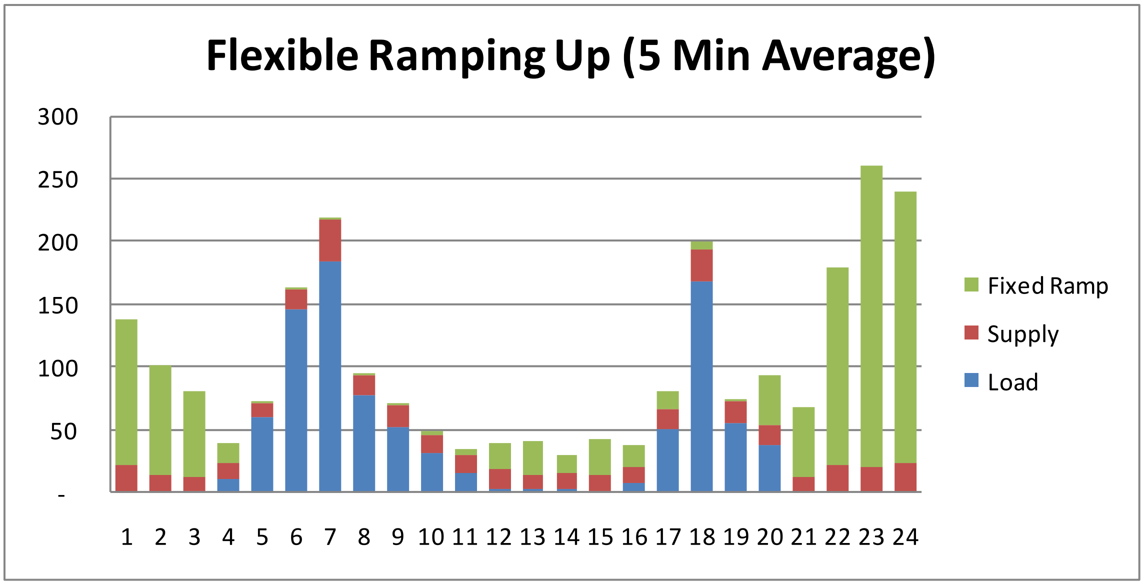


FIGURE 16 - AVERAGE FRU USING ESTIMATED 5 MINUTE MOVEMENT

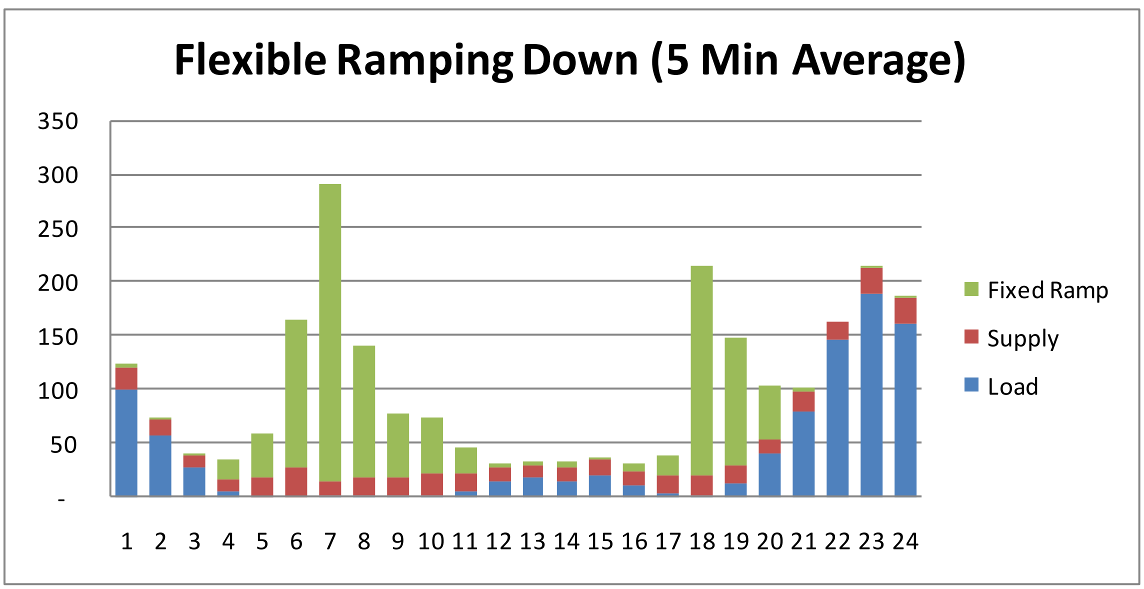


FIGURE 17 - AVERAGE FRD USING ESTIMATED 5 MINUTE MOVEMENT

The ISO has also posted an updated 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 15 – 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 change in uninstructed deviations. For the initial split between the categories, all supply resources will be measured using the change in uninstructed imbalance energy.

Within the category, conventional generation deviations will be measured based upon changes in uninstructed imbalance energy. Variable energy resources can elect to be measured based upon changes in their deviation to their 15 minute real-time forecast made 37.5 minutes prior to the RTPD interval. If a variable energy resource elects to not use the 15 minute forecast, then its allocation will be based upon changes in uninstructed imbalance energy.

The use of the change in uninstructed deviations recognizes that the ramp requirement only occurs once. For example, assume a resource negatively deviates 10 MW for the entire hour. Once the deviation occurs, another resource must be dispatched up 10 MW to make up the shortfall; however, no additional ramp is required to address the subsequent uninstructed deviations. When the resource stops deviating and returns to its schedule, the other resource must be dispatched down 10 MW.

The ISO is still evaluating implementation complexity allocating the supply category based upon changes in uninstructed deviations. Since 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 more precise, the ISO gross UIE can be a close approximation. The ISO has posted a model that stakeholders can use to assess the different allocation metric within the supply category. The ISO will complete the implementation assessment shortly. The final decision between delta UIE and gross UIE will be made in the next paper. This implementation concern only applies to the allocation of the supply category. The initial allocation to each of the three categories will be based upon delta UIE for supply resources.

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. As a result, the 10 minute change in UIE1 and UIE2 will be counted towards the allocation of flexible ramping costs because other resources will have to be dispatched to address those deviations.

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 use the real-time forecast of variable energy resources (both PIRP and non-PIRP) if the resource elects this option. If a variable energy resource does not select this option, the measurement on uninstructed energy will be the same as conventional generation which is based upon schedule and dispatch. 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.

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.

Previously, the ISO proposed to allow variable energy resources to submit their own expected energy output. 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. In addition, CalWEA expressed concerns regarding additional complexity for variable energy resources and that resources could incur additional costs in order to provide the expected energy output. As a result, the ISO now proposes to use the third party ISO forecast for the baseline for measuring changes in uninstructed energy. The same forecast will be utilized in RTUC as part of the PIRP DEC bidding discussed in Section 5.

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 ISO will consider allowing VERs to submit their own 15 minute expected energy as the gaming concerns would 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. State 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.

Preliminary analysis by the ISO shows that using a threshold will not result in the need to consider a two-tiered allocation for the supply category. 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. If a two tiered allocation were required, the second tier costs would have to be recovered by only resources within the supply category. The threshold is only applied after the costs are split in to each of the three categories. The threshold is only proposed for the allocation of costs from the supply category.

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. Internal self-schedules require the ISO to manage dispatchable resources to honor the resource's ramp rate between hourly schedules. Internal generation can avoid the fixed ramp allocation by submitting a real-time economic bid. The submission of the economic bid allows the ISO to dispatch the resource if the modeled ramp between hourly schedules is not aligned with system conditions. This reduces the flexible ramping product procurement target and increases the pool of resources available to meet the flexible ramping product procurement target.

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 has posted movement data for internal self-schedules. The internal-self schedules are approximately 80% of the total fixed ramp category.

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. 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.

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.

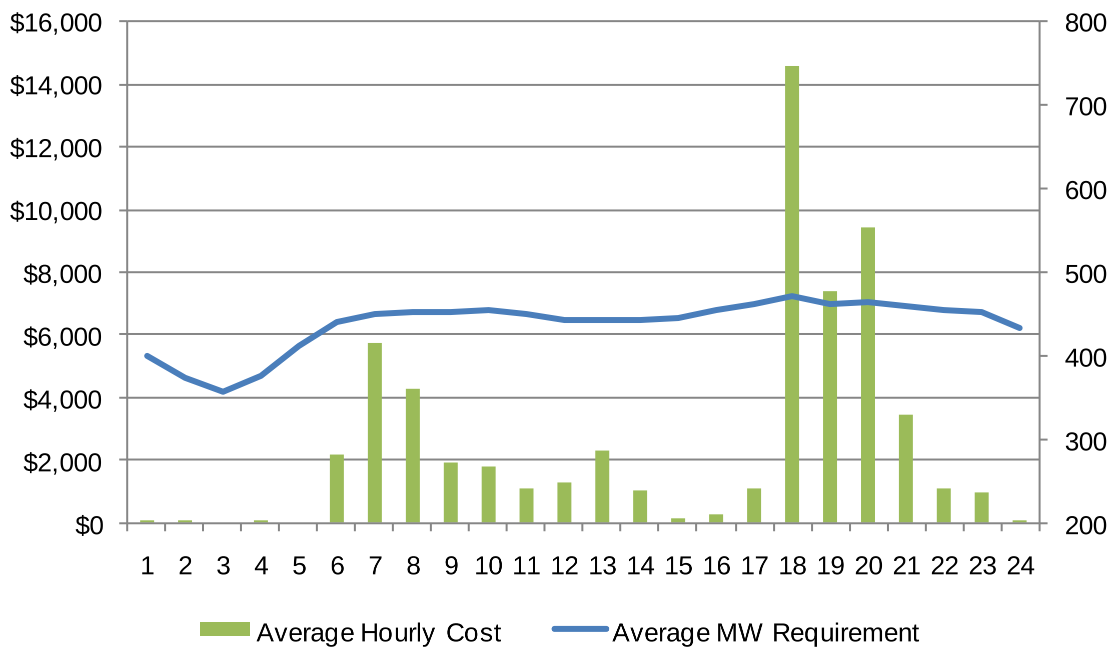


FIGURE 18 - HOURLY FLEXIBLE RAMPING CONSTRAINT COSTS JANUARY TO MARCH 2012

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 (60%), the supply category would be $1.0 million (19%), and fixed ramps would be $1.2 million (21%).

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 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 Revised Draft Final Proposal	August 9, 2012
Stakeholder Meeting	August 16, 2012
Stakeholder Comments Due	August 23, 2012
Post 2nd Revised Draft Final Proposal	September 11, 2012
Stakeholder Meeting	September 18, 2012
Stakeholder Comments Due	September 25, 2012
Board of Governors Meeting	November 1-2, 2012

NEXT STEPS

The ISO will discuss the special edition with stakeholders at a meeting to be held on August 16, 2012. The ISO is seeking written comments on the revised straw proposal by August 23, 2011. Stakeholder comments should be sent to FRP@caiso.com.

APPENDIX A: NOMENCLATURE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$FRDP_t$ shadow price of downward flexible ramping constraint at time interval t

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

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

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

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

α regulation ramp sharing coefficient

β spinning reserve ramp sharing coefficient

γ flexible ramping product ramp sharing coefficient

η non-spinning reserve ramp sharing coefficient

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

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

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

The stylized/simplified model in this section is for illustration purpose only, and may not reflect the actual implementation model. The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[9] 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,[10] 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.

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

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.

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

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.

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

---

[9] 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.

[10] 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.

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

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.

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

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[11].

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

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

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

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