Flexible Ramping Products

Straw Proposal

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1. INTRODUCTION

This paper will describe the ISO's proposal to define the upward and downward flexible ramping products. The purpose of this stakeholder effort is to develop market-based flexible ramping products to address the operational needs in real-time market facing the upcoming challenges from increasing renewable penetration. Prior to these market-based full flexible ramping products, the ISO has proposed to implement a flexible ramping constraint to address certain reliability and operational issues observed in the ISO's operation of the grid.[1] Upon the completion of the Flexible Ramping Constraint stakeholder process, the ISO recognized that greater market efficiencies can be gained by developing market-based products that allow for the identification, commoditization and compensation for the needed flexible capability. The ISO has observed that the unit commitment and position of units in the real-time pre-dispatch process (RTPD), also known as the real-time unit commitment process, sometimes lack sufficient ramping capability and flexibility to meet conditions in the five-minute real-time dispatch (RTD) during which conditions may have changed from the assumptions made during the prior pre-dispatch. The flexible ramping products to be developed in this stakeholder process will target the discrepancies between the RTPD and RTD, which are uncertainties from the RTPD point of view, and are realized in the RTD. Market participants will be allowed to offer ramping capabilities into the market, and the ISO will optimize such offers to economically meet the anticipated ramping need. In order to better demonstrate the purpose and characteristics of the flexible ramping products to be developed in this process, this document includes a discussion of prospective products in the context of the existing processes and ancillary services products.

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

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

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

If a major contingency happens, the operator may choose to perform a special process, the real-time contingency dispatch (RTCD), to economically deploy operating reserves (spinning reserve

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

and non-spinning reserve) in order to restore the system back to normal operating conditions. RTCD performs both unit commitments and dispatches on a 10-minute interval basis.

At the actual delivery time, a system imbalance will manifest itself in system frequency or area control error (ACE), and will trigger the utilization of automatic generation control on resources that are awarded regulation services in day-ahead for the corresponding hour or in RTPD for the corresponding 15-minute interval.

Electricity is different from other commodities in that it is produced and consumed instantaneously, and both supply and demand are constantly changing. These properties pose a great challenge to the ISO to maintain power balance every minute and every second. That is why it is necessary to have temporal hierarchical processes to look ahead at future supply and demand conditions, and reserve dispatchable capacities as ancillary services. Currently, the look-ahead is performed in a deterministic way to balance expected supply and expected demand in the future. Assuming the load forecast and resource schedules are close to their expected values, this approach should work well. The electric power industry has been operated in this way for a long time. However, with the increased amount of variable energy resources, whose actual outputs may vary, and cannot be accurately forecasted, looking ahead at expected values may cause operational difficulties, a reliability concern. In order to operate the grid reliably, the ISO proposes to define the flexible ramping products, which provides a market mechanism for procuring sufficient ramping capability to handle certain variability and uncertainties.

As illustrated in Figure 1, uncertainties are classified into two categories according to the time they are realized. Certain uncertainties are realized after RTPD and before RTD. These post RTPD uncertainties include load forecast changes, variable energy resources production changes, and other changes between RTPD and RTD. The post RTPD uncertainties are realized before the RTD dispatches, so RTD dispatches can "recourse"[2] according to the realizations. Another type of uncertainties is realized after RTD runs. These post RTD uncertainties include deviations of actual load from RTD load forecast, uninstructed deviations, small outages which happen in real-time, and so on. Because RTD is the last opportunity for sending out dispatches under normal operating conditions, the post RTD uncertainties once realized will only be handled by automatic generation controls (AGC), which are procured in day-ahead or corresponding RTPD as regulation services. The difference between post RTPD uncertainties and post RTD uncertainties and how to address them are illustrated in Figure 2.

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

The flexible ramping products are targeted at handling the post RTPD uncertainties, i.e. the deviations of supply and demand between RTPD and RTD. The ISO intends to procure the flexible ramping products in both day-ahead market and in RTPD. Flexible ramping products requirements in both day-ahead market and RTPD will be based on anticipated variations and uncertainties between RTPD and RTD. Given the flexible ramping products requirements, the day-ahead market and RTPD will make unit commitment and flexible ramping procurement decisions to ensure there is sufficient ramping capability in the system to handle the uncertainties that are realized in RTD.

This straw proposal will focus on a high level description of the core flexible ramping products design. As the stakeholder process goes, more details about resource qualifications, bidding rules, settlements, multi-stage generator (MSG) modeling, and other relevant matters will be added to complete the proposal.

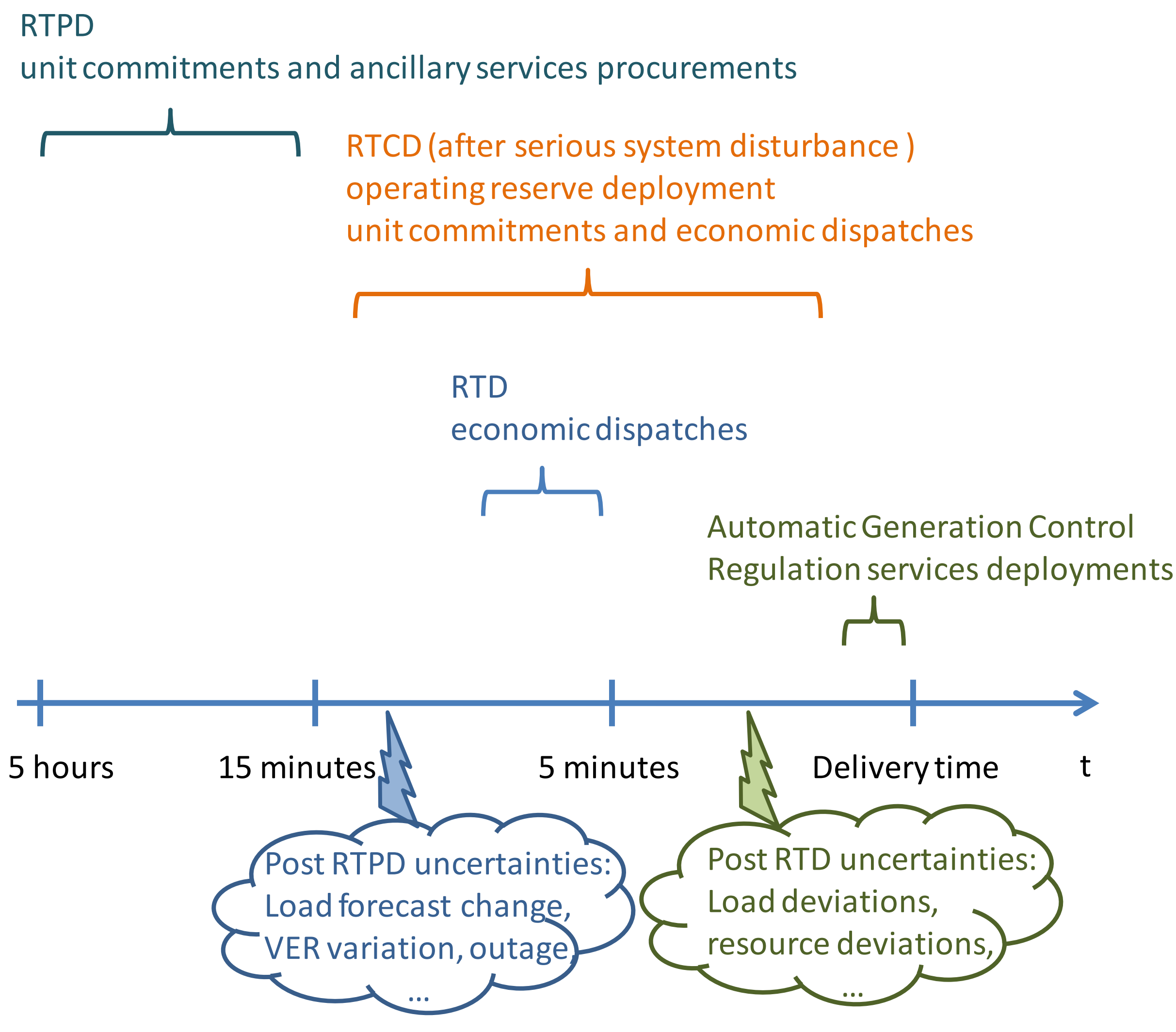

FIGURE 1: REAL-TIME MARKETS TIME FRAME

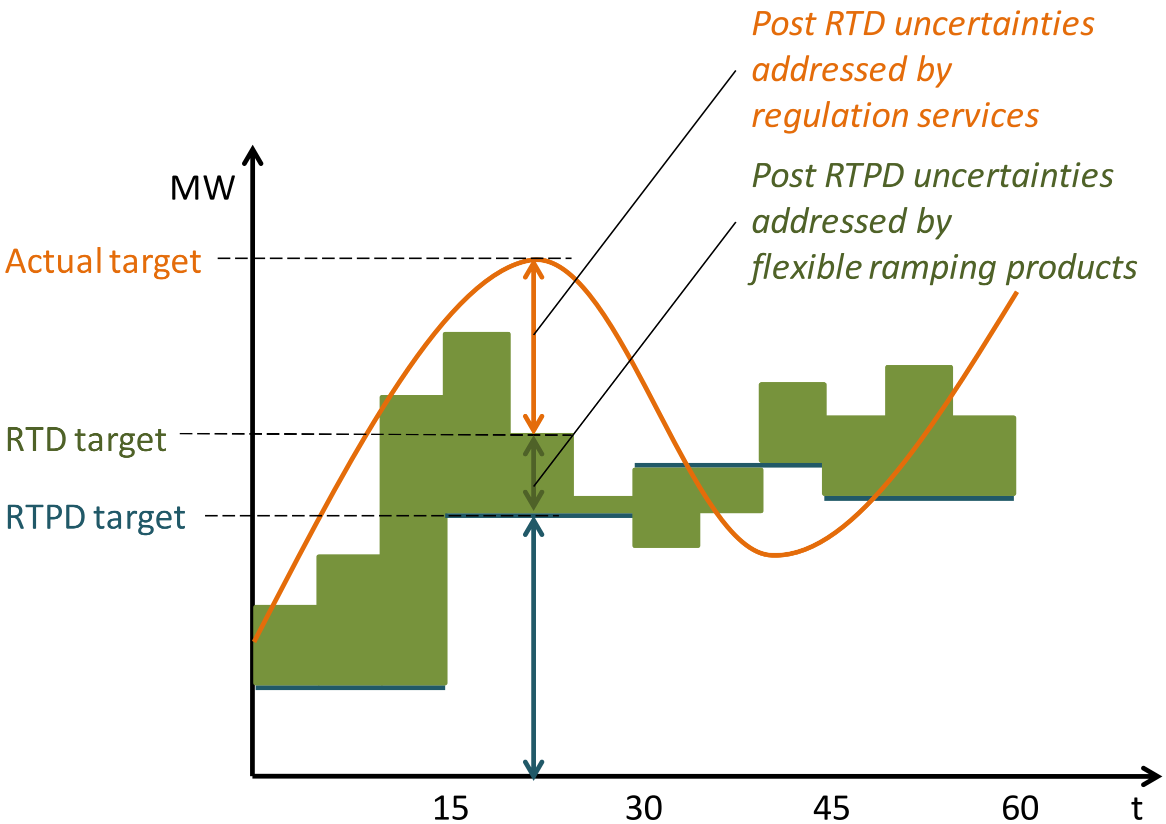

FIGURE 2: HANDLING UNCERTAINTIES WITH FLEXIBLE RAMPING PRODUCTS AND REGULATION SERVICES

2. FLEXIBLE RAMPING PRODUCTS DESIGN

The flexible ramping products are designed to deal with the uncertainty between the RTPD and the RTD. The uncertainties may come from load forecast difference, changes of production levels from variable energy resources, and other changing factors. From a stochastic programming point of view, faced with those uncertainties, RTPD will commit and dispatch units differently than without those uncertainties. With uncertainties, a stochastic program would commit more flexible units, position units at faster ramping dispatch levels in anticipation of rapid imbalance changes in RTD. The current technology does not allow detailed modeling of those uncertainties and solving stochastic programs in real-time. The flexible ramping products are created as a heuristic way to mimic what a stochastic program would do to deal with those uncertainties. In other words, the flexible ramping products will be able to commit fast ramping units, and position units at fast ramping dispatch levels. The flexible ramping products awards will be compensated according to the marginal prices in the procurement processes. The preserved ramping capabilities may be deployed in RTD. If they are deployed, the deployed portion, which has been converted to energy schedules, will also receive RTD energy payments.

Because RTD is on a 5-minute interval basis, the flexible ramping product is also a 5-minute ramping product[3] meaning that the flexible ramping product award is limited by how much a resource can ramp within 5 minutes. This is to ensure that the procured flexible ramping products can be fully deployed in one RTD interval when they are needed.

The flexible ramping consists of separate products in the upward and downward direction. The market will accept bids on both products, which express the resources' willingness to provide flexible ramping, and the cost associated with them. The upward bid can be different from the downward bid. Like ancillary services, a flexible ramping bid will only have one bid segment. The ISO will only procure flexible ramping from the resources that put bids on the flexible ramping products. Also, resources that submit flexible ramping products bids must also submit an economic energy bid. Otherwise, the flexible ramping bids will be rejected.

2.1 COOPTIMIZING FLEXIBLE RAMPING PRODUCTS WITH ENERGY AND ANCILLARY SERVICES IN RTPD

This section will cover the stylized optimization model of co-optimizing the flexible ramping products with energy and ancillary services in RTPD. In RTPD, the procured operating reserves are contingent regardless whether the resources are flagged as contingent only or not, so there is no substitution between the flexible ramping products and contingent reserves in RTPD. Non-contingent reserves need additional modeling to allow substitution between non-contingent spinning reserve and flexible ramping products. How to model the substitution between non-contingent reserves and the flexible ramping products will be discussed in detail in the next version of this proposal. Also, we will defer the discussion of how to procure flexible ramping products in the day-ahead market to the next version because it is closely related to non-contingent reserve modeling.

[3] The flexible ramping products procurement in day-ahead is on an hourly basis, and in RTPD on 15-minute interval basis.

The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[4] 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,[5] which is a function of the generation output level, and the following model can be generalized to dynamic ramp rates without problem. As a convention, assume ramp rates are specified in MW/minute.

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

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

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

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

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

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

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

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

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

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

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[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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Just like energy requirement and ancillary services requirements, the flexible ramping products requirement constraints will be allowed for relaxation to a certain extent at appropriate penalty prices.

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

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

Charge on uncertainty *u* that incurs flexible ramping need is $\lambda_t^{FRU} \cdot R_{u,t}^{FRU}$, and the total charge is $\lambda_t^{FRU} \cdot \sum_{u \in UU} R_{u,t}^{FRU}$.

Because the procurement should be greater or equal to the requirement,

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

This means the ISO is revenue adequate.

If there is no flexible ramping scarcity, then $\sum_{u \in UU} R_{u,t}^{FRU} = \sum_{i \in I_{FR}} FRU_{i,t}$, which implies the total charge is equal to the total payment:

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

Therefore, the ISO should be revenue neutral under normal conditions.

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

2.2 DEPLOYING FLEXIBLE RAMPING IN RTD

In RTD, uncertainties are realized. The procured flexible ramping products will be deployed to recourse the dispatches accordingly. In RTPD, the flexible ramping products are procured on a 15-minute interval basis, and should deal with uncertainties that happen within this 15-minute interval, which covers three 5-minute binding RTD intervals. RTD runs every 5 minutes, so the uncertainties are not fully realized in the first RTD run or the second RTD run. This means the flexible ramping capability should not be depleted in the first or the second binding RTD intervals unnecessarily, i.e. not because of real ramping need but because the bids are economic. One way to prevent the flexible ramping capability being depleted before the uncertainties are fully realized in the third RTD run is to protect the flexible ramping capability using a constraint penalty. This is mathematically equivalent to protecting the flexible ramping capability by establishing a cost adder to the energy bids so that the energy bids supporting the flexible ramp capability appears to be more expensive, and less likely to be depleted. However, this approach has one major issue. That is, the penalty price may contaminate the RTD energy prices. In other words, the RTD energy prices are not determined using market bids, but using market bids with arbitrary adders. This makes the RTD energy prices higher than the true economic prices. More seriously, because the procured ramping capability is already fully compensated in RTPD, economically withholding it will incur additional system cost in RTD, and affect market efficiency inadvertently.

Instead, the ISO proposes the following way to deploy flexible ramping products in RTD. The flexible ramping capabilities are procured in RTPD to handle the RTD uncertainties. Therefore, after the uncertainties are realized in RTD, the needed deployment of flexible ramping product is at most the total amount of realized uncertainties. Equivalently this means the remaining flexible ramping capabilities in RTD should be greater than or equal to the difference between RTPD requirements minus the total amount of realized uncertainties, which can be modeled as the following constraints:

$$R_t^{FRU,RTPD} - R_t^{FRU,RTD} \leq \sum_{i \in I_{FR}} FRU_{i,t}^{RTD}$$

$$FRU_{i,t}^{RTD} \leq FRU_{i,t}^{RTPD}$$

$$R_t^{FRD,RTPD} - R_t^{FRD,RTD} \leq \sum_{i \in I_{FR}} FRD_{i,t}^{RTD}$$

$$FRD_{i,t}^{RTD} \leq FRD_{i,t}^{RTPD}$$

Note that the unreleased flexible ramping products are still variables to be determined in the RTD dispatch, while the released flexible ramping products will be converted to energy schedules.

There are several important properties in the ISO's proposed deployment method.

1) There is no economic withholding effect of the flexible ramping capability to handle the realized uncertainties.

2) RTD energy price will be determined by true market bids, and will not be contaminated by arbitrary penalty prices to protect the flexible ramping capabilities.

3) Procured flexible ramping capabilities will not be used for purposes other than handling RTD uncertainties. If a significant ramping need is not realized in an earlier RTD interval (the first or the second), flexible ramping capabilities will be preserved for later use. If a significant ramping need is realized in an earlier interval (the first or the second), flexible ramping capability may be restored in a later RTD interval, so that the real ramping capabilities can be preserved into the next RTPD binding 15-minute interval to be re-procured if they are needed. Being able to restore the ramping capability is a very important feature for the periodically performed real-time optimizations.

3. EXAMPLE

In this section, a numerical example will be discussed to illustrate how the flexible ramping products interact with energy and ancillary services, how they are priced, and how they are settled.

3.1 A THREE-GENERATOR EXAMPLE

There are three units in the system: G1, G2, and G3. For simplicity, consider only one interval in RTPD with $T = 1$, and neglect the transmission network impacts and power losses.

The requirements are

- load is 300 MW,
- regulation up requirement is 10 MW,
- regulation down requirement is 10 MW,
- spinning reserve requirement is 25 MW,
- non-spinning reserve requirement is 0 MW,
- upward flexible ramping product requirement is 20 MW (15 MW from load and 5 MW from variable energy resources), and
- downward flexible ramping product requirement is 8 MW (5 MW from load and 3 MW from variable energy resources).

The ramp sharing coefficients are

- $\alpha = 0.75$, which means ramp sharing between regulation and energy is not allowed,
- $\beta = 0$, which means ramp sharing between spinning reserve and energy is allowed,
- $\gamma = 1.5$, which means ramp sharing between flexible ramping product and energy is not allowed,
- $\eta = 0$, which means ramp sharing between non-spinning reserve and energy is allowed.

The bids and generator parameters are listed in Table 1 and Table 2.

gen	EN Bid	RU bid	RD bid	SP bid	NS bid	FRU bid	FRD bid	En init	RU init	RD init	SP init	NS init	FRU init	FRD init
G1	30	2	2	0	0	0	0	195	0	10	5	0	0	8
G2	35	2	2	0	0	0	0	85	0	0	10	0	0	0
G3	50	1	1	0	0	0	0	10	10	0	5	0	20	0

TABLE 1: BIDS AND GENEARTOR INITIAL OPERATING CONDITIONS

gen	Pmin	Pmax	operational ramp rate	regulation ramp rate
G1	10	200	3	3
G2	10	300	1	1
G3	10	50	5	5

TABLE 2: GENERATOR OPERATING AND RAMP RATES

3.2 PROCURING FLEXIBLER RAMPING PRODUCTS IN RTPD

Given the system requirements, the optimal RTPD schedules of energy, ancillary services and flexible ramping products are listed in Table 3.

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	195	0	10	5	0	0	8
G2	95	0	0	10	0	0	0
G3	10	10	0	10	0	20	0

TABLE 3: OPTIMAL SCHEDULES

In addition, the shadow prices of all the requirements and the corresponding price setters are discussed in detail as follows. The price setters are highlighted in colors: red color means increasing from the optimal schedules in Table 3, and blue color means decreasing from the optimal schedules in Table 3.

1. Energy balance requirement shadow price is $35/MWh. If load is increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	195	0	10	5	0	0	8

G2	96	0	0	10	0	0	0
G3	10	10	0	10	0	20	0

2. Reregulation up marginal price is $6/MWh. If regulation up requirement is increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	194	0	10	6	0	0	8
G2	96	0	0	9.5	0	0.5	0
G3	10	11	0	9.5	0	19.5	0

3. Regulation down marginal price is $2/MWh. If regulation down requirement is increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	195	0	11	5	0	0	8
G2	95	0	0	10	0	0	0
G3	10	10	0	10	0	20	0

4. Spinning reserve $5/MWh. If spinning reserve requirement increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	194	0	10	6	0	0	8
G2	96	0	0	10	0	0	0
G3	10	10	0	10	0	20	0

5. Non-spinning $5/MWh. If non-spinning reserve requirement increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule

G1	194	0	10	6	0	0	8
G2	96	0	0	10	0	0	0
G3	10	10	0	9	1	20	0

6. Upward flexible ramping product marginal price is $5/MWh. If upward flexible ramping requirement is increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	194	0	10	6	0	0	8
G2	96	0	0	9	0	1	0
G3	10	10	0	10	0	20	0

7. Downward flexible ramping product marginal price is $0/MWh. If downward flexible ramping requirement is increased by 1 MW, the revised optimal schedules will be

gen	En schedule	RU schedule	RD schedule	SP schedule	NS schedule	FRU schedule	FRD schedule
G1	195	0	10	5	0	0	9
G2	95	0	0	10	0	0	0
G3	10	10	0	10	0	20	0

This example demonstrates that the flexible ramping products, energy schedules, and ancillary services are all linked together through the co-optimization, and the marginal prices will reflect all opportunity costs. For example, although the bids of upward flexible ramp products are all zeroes, the marginal price is not zero.

3.3 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

For every binding RTPD 15-minute interval, the procured flexible ramping products will be settled at the cleared amount times the corresponding shadow price. For this one 15-minute RTPD interval in the example, payments to the flexible ramping providers are

gen	FRU schedule	FRD schedule	payment

G1	0	8	0.25*(0*5+5*0) = $0
G2	0	0	0.25*(0*5+3*0) = $0
G3	20	0	0.25*(20*5+8*0) = $25
total	20	8	0.25*(20*5+8*0) = $25

Charges to the flexible ramping consumers are

uncertainty	upward	downward	charge
load	15	5	0.25*(15*5+5*0) = $18.75
variable energy resources	5	3	0.25*(5*5+3*0) = $6.25
total	20	8	0.25*(20*5+8*0) = $25

As shown above, the total payment equals the total charge, so the ISO is revenue neutral.

3.3 DEPLOYING FLEXIBLE RAMPING PRODUCTS IN RTD

For simplicity, assume a single interval dispatch in RTD, and the generator are all following instructions. Assume the total amount of uncertainties is realized in the three 5-minute RTD runs in the following way:

Realized total uncertainty	upward	downward
RTD1	3	0
RTD2	18	0
RTD3	6	0

Because G3 has a higher energy bid than the energy marginal resource G2, in RTD G2 will dispatched before G3 to meet deviations from the RTPD. G2's ramp rate is 1 MW/min, so it can provide at most 5 MW every 5 minutes. Therefore, in the first RTD dispatch where the realized deviation is 3 MW, G2 is able to meet it without dispatching procured flexible ramping from G3.

RTD1:

gen	En schedule	FRU schedule	FRD schedule
G1	195	0	8

G2	98	0	0
G3	10	20	0

LMP = $35/MWh

The second RTD interval has 15 MW of ramping need from the first RTD interval, so G2 along is not able to meet it due to its ramping limitation. The upward flexible ramping from G3 is deployed to maintain power balance. The solution is that G2 provides 5 MW incremental energy, and G3 converts 10 MW upward flexible ramping capability into incremental energy to meet the need of total 15 MW.

RTD2:

gen	En schedule	FRU schedule	FRD schedule
G1	195	0	8
G2	103	0	0
G3	20	10	0

LMP = $50/MWh

The deviation from RTPD drops to 6 MW in the third RTD interval. Because G2 is able to meet this deviation, the upward flexible ramping from G3 is restored to its full procured capability 20 MW. This makes G3's flexible ramping capability available for future use.

RTD3:

gen	En schedule	FRU schedule	FRD schedule
G1	195	0	8
G2	101	0	0
G3	10	20	0

LMP = $35/MWh

This example demonstrates:

1. Procured flexible ramping product will not be deployed more than the total amount of realized uncertainties.

2. If there is cheaper energy from the rest of the dispatchable fleet, the ramping capability from the cheaper fleet will be utilized before procured flexible ramping product is deployed.

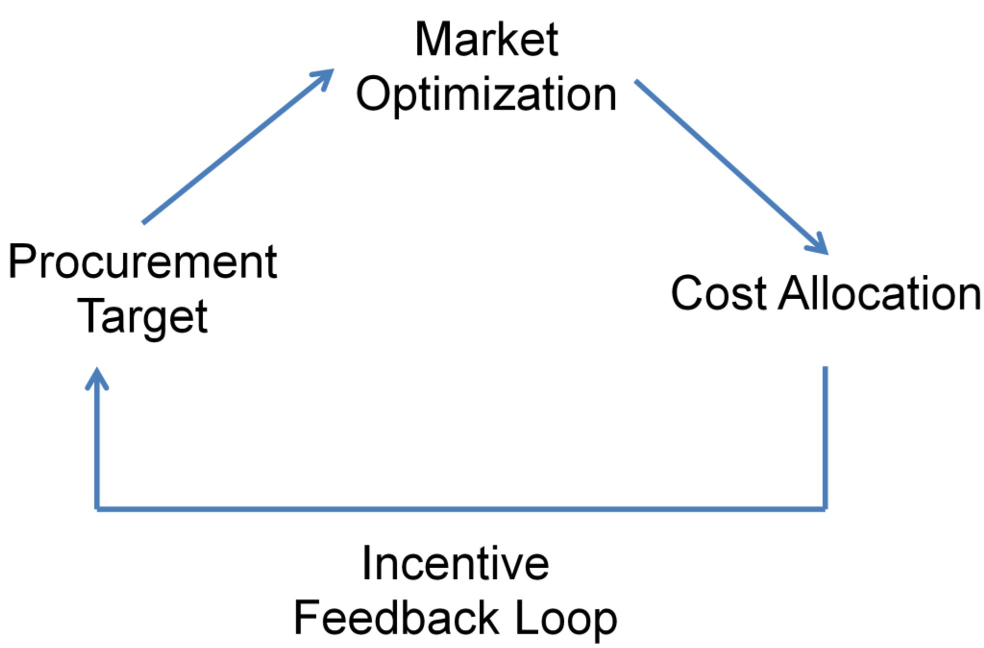
3. Procured flexible ramping product can be restored if the ramping need drops.

1. COST ALLOCATION

4.1 OVERVIEW

The design of cost allocation mechanisms should create the correct incentives for resources which lead to lower procurement targets of operating reserves. The procurement target should be reduced over time as the cost allocation provides feedback to the resource's impact on the procurement target. The resource is able to benefit from reducing the underlying drivers that lead to the procurement of operating reserves which in turn reduces future requirements for the operating reserve. In the case of the flexible ramping product, if resources are able to minimize variability and uncertainties between RTPD and RTD, the procurement target could be reduced over time which would lead to enhanced grid reliability, improved market efficiency, and lower overall costs.

FIGURE 3 – COST ALLOCATION FEEDBACK LOOP



By allocating costs to resources that cause the procurement of the flexible ramping product, a resource seeking to maximize profit in the energy market would make efforts to minimize their exposure to flexible ramping cost allocations. In addition, the cost allocation provides additional information for use in bilateral contracts to reduce the costs of load serving entities to achieve their resource adequacy and RPS requirements.

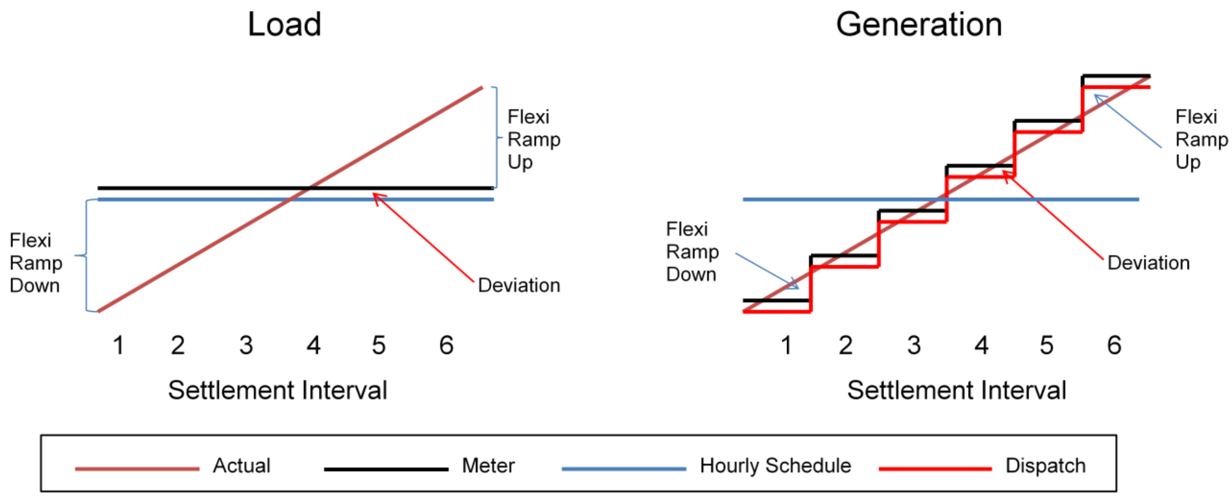
Consistent with stakeholder comments in the Renewable Integration - Market Vision and Roadmap stakeholder initiative, for mid-term initiatives, the ISO is seeking to make evolutionary changes versus a wholesale redesign of existing market systems of both the ISO and market participants. As a result, the ISO has sought to use existing settlement and metering data to design a flexible ramping cost allocation that is consistent as possible with cost causation. For example, while deviations from five minute schedules may allow the most accurate allocation of flexible ramping costs, meter data does not currently allow the measurement of deviations at this level of granularity. Internal generation is metered on a ten minute basis, load is metered on an hourly basis and imports/exports are metered on an hourly basis. In addition, while flexible ramping is procured to address system variability between RTPD and RTD, energy schedule data for RTPD is only advisory and not financially binding which diminishes the effectiveness its use as a reference point to measure deviations. While the ISO is seeking to use existing settlement and metering data, the implementation of the proposed cost allocation will result in software changes to existing settlement software and changes in business processes.

The cost allocation design discussion for flexi-ramp will be used to identify additional market design changes necessary to implement more advanced allocation methodologies. The development of a more advanced allocation methodology will most likely require significant market design changes that result in the alignment of scheduling, metering and settlement intervals across all resources participating in the market.

4.2 METER GRANULARITY

Since both load and generation are considered in the procurement target for flexible ramping, a consistent metering interval would be necessary to implement a single allocation to both load and generation. However, load is metered hourly and internal generation is metered on a ten minute basis. As illustrated in Figure 2 below, while load and generation have similar deviations based upon their meter, actual load would drive a larger portion of the flexible ramping product procurement requirements. Thus existing meter data for load would under allocate costs to load and over allocate costs to generation.

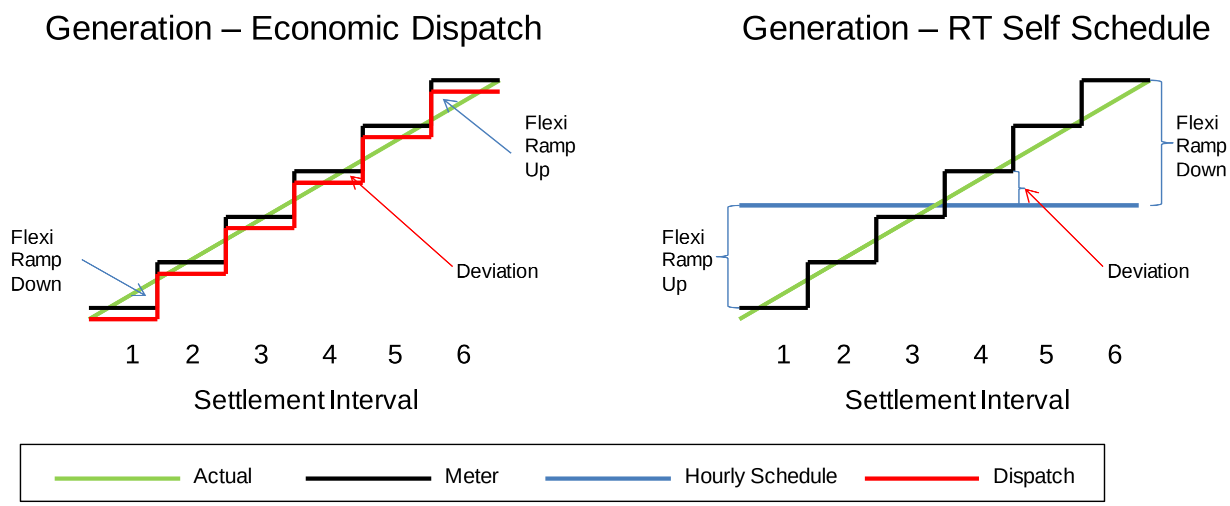
FIGURE 4 - COMPARISON OF LOAD AND GENERATION DEVIATIONS



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

However, when determining the deviations for generation and imports it is necessary to further segment generation in to two groups. The reference point to measure deviations by supply is not aligned for all resources. For resources that respond to five minute dispatch the deviation should be measured from their instructed energy and not the hourly schedule. The reference point to measure deviations for generation with self schedules in real time would be the hourly schedule. In addition, reference point of imports would be the hourly schedule. It would be inappropriate to allocate flexible ramping costs to generation which has deviated from its hourly schedule in response to ISO dispatch. As figure 3 below shows, self scheduled generation which deviates is driving a larger flexible ramping procurement target than a generation resource which has responded, although not perfectly, to ISO dispatch.

FIGURE 5 - COMPARISON OF GENERATION WITH ECONOMIC DISPATCH AND SELF SCHEDULES



The ISO proposes to create a separate cost allocation for flexible ramping up and flexible ramping down. The costs for procuring flexible ramping in the day-ahead market and real-time market will be combined into a single allocation for each direction.

Because of the different reference points to measure deviations, the ISO proposes to further segment the costs in to three buckets: (1) costs attributable to load, (2) costs attributable to deviations from hourly schedules, and (3) costs attributable to deviations from ISO dispatch. Flexible ramping up costs will be allocated to negative deviations. Flexible ramping down costs will be allocated to positive deviations. Positive and negative deviations will not be allowed to net across settlement intervals to reduce flexible ramping cost allocations. However, within the settlement interval the deviations will net, that is a positive deviation in the first five minute dispatch would offset a negative deviation in the second five minute interval given that the meter interval is ten minutes. Since the reference point used to measure deviations is the same within each of the three buckets, the impact of netting within the settlement interval will similarly affect all resources in determining their cost allocation for a specific bucket. The costs will be allocated at a resource level, not aggregated by scheduling coordinator, because the objective is resource specific feedback on its impact to the flexible ramping procurement target.

4.3 SETTLEMENT CHARGES TO MEASURE DEVIATIONS

TABLE 4 - SETTLEMENT CALCULATION FOR COST ALLOCATION

Bucket	Allocation
UP – Load	Measured Demand (Metered Load + Exports)
UP – Hourly Schedule	Negative Uninstructed Imbalance Energy 2 Negative Operational Adjustments 1 & 2 (Imports)

UP – Dispatch	Negative Uninstructed Imbalance Energy 1
DOWN – Load	Measured Demand (Metered Load + Exports)
DOWN – Hourly Schedule	Positive Uninstructed Imbalance Energy 2 Positive Operational Adjustments 1 & 2 (Imports)
DOWN – Dispatch	Negative Uninstructed Imbalance Energy 1

Table 1 above summarizes the settlement charges for each of the flexible ramping buckets. The ISO will use the gross sum of each deviation to allocate each flexible ramping cost on a pro rata basis for each resource. For example, assume the total monthly cost for flexible ramping up product is $10,000. The procurement target attributable to load is 60%, deviation to hourly schedule is 30% and deviation to dispatch is 10%. Therefore, the flexible ramping cost recovered from load is $6,000, from deviation to hourly schedule is $3,000, and from deviation to dispatch is $1,000. For allocation to individual resources, the monthly cost for UP-Dispatch is $1000, assume the total negative deviations are 500MWh, a resource which had Negative Uninstructed Deviation 1 of 50MWh would be allocated $100 of UP-Dispatch cost.

Uninstructed imbalance energy 1 represents the deviation from the resources instructed imbalance energy. Uninstructed imbalance energy 2 represents any remaining deviation of the resource attributed to its day-ahead schedule and real-time self schedule. The following tables provide high level examples of how uninstructed imbalance energy types are calculated. Since both types of operational adjustments are included in a single cost bucket, an example has not been included which calculates the two types of operational adjustments. Additional information can be found in the Settlement Business Practice Manual (BPM)[7].

TABLE 5 - GENERATION WITH DA SCHEDULE AND RT INSTRUCTIONS

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Day Ahead Schedule (DA)	100	100	100	100	100	100	100	100
Real Time Self Schedule (RT SS)	0	0	0	0	0	0	0	0
Instructed Imbalance Energy (IIE)	10	10	10	10	-10	-10	-10	-5
Dispatch (DA + RT SS + IIE)	110	110	110	110	90	90	90	95
Meter	110	100	90	120	90	80	100	110
Imbalance Energy (Meter - DA)	10	0	-10	20	-10	-20	0	10
Imbalance Energy - IIE - RT SS	0	-10	-20	10	0	-10	10	15
Uninstructed Imbalance Energy 1	0	-10	-10	0	0	0	10	5
Uninstructed Imbalance Energy 2	0	0	-10	10	0	-10	0	10
Uninstructed Imbalance Energy	0	-10	-20	10	0	-10	10	15

[7] Settlements and Billing BPM is available at https://bpm.caiso.com/bpm/bpm/version/000000000000085

TABLE 6 - GENERATION WITHOUT DA SCHEDULE AND NO RT INSTRUCTIONS

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Day Ahead Schedule (DA)	0	0	0	0	0	0	0	0
Real Time Self Schedule (RT SS)	100	100	100	100	100	100	100	100
Instructed Imbalance Energy (IIE)	0	0	0	0	0	0	0	0
Dispatch (DA + RT SS + IIE)	100	100	100	100	100	100	100	100
Meter	110	100	90	120	90	80	100	110
Imbalance Energy (Meter - DA)	110	100	90	120	90	80	100	110
Imbalance Energy - IIE - RT SS	10	0	-10	20	-10	-20	0	10
Uninstructed Imbalance Energy 1	0	0	0	0	0	0	0	0
Uninstructed Imbalance Energy 2	10	0	-10	20	-10	-20	0	10
Uninstructed Imbalance Energy	10	0	-10	20	-10	-20	0	10

4.4 SETTLEMENT TIMING OF FLEXIBLE RAMPING COSTS

Since flexible ramping is procured based upon forecasted variability and uncertainty, when a resource deviates in a specific settlement interval, it cannot be concluded that the resource's actual deviation caused the flexible ramping product to be procured for that settlement interval. As a result, the ISO proposes to allocate the cost of flexible ramping due generation and imports based upon the total cost and total deviations for the month. At the end of the month, generation and import resources will be allocated their pro rata share for flexible ramping costs based upon their total gross deviations over the month.

Inter-SC trades currently support the daily transaction of energy, residual unit commitment obligation, and ancillary services obligation, between scheduling coordinators. The ISO is considering expanding the inter-SC trade functionality to allow the monthly transaction of the flexible ramping product obligation.

The ISO proposes to allocate all flexible ramping costs to measured demand over the course of the month. At the end of the month, the ISO will allocate the monthly costs attributable to generation and imports. The costs received from generation and imports will then be credited to measured demand.

4.5 FLEXIBLE RAMPING COST DATA RELEASE

The ISO proposes to publish on a daily basis the month to date flexible ramp cost procured, the MWh deviations subject to cost allocation, and the per MWh rate of deviations. The data will be provided for both flexible ramping up and flexible ramping down and for each of the three cost allocation buckets. The data will inform resources of the current flexible ramping cost allocation associated with deviating from its schedule or ISO instruction.

2. PLAN FOR STAKEHOLDER ENGAGEMENT

Item	Date
Post Straw Proposal	10/31/11
Stakeholder Meeting	11/7/11
Stakeholder Comment	11/14/11
Post Revised Straw Proposal	11/28/11
Stakeholder Meeting	12/5/11
Stakeholder Comment	12/12/11
Post Draft Final Proposal	01/05/12
Stakeholder Meeting	01/12/12
Stakeholder Comment	01/19/12
Board of Governors	02/16/11

3. NEXT STEPS

The ISO will discuss the Straw Proposal with stakeholders at a meeting to be held on November 7, 2011. The ISO is seeking written comments on the straw proposal by November 14, 2011. Stakeholder comments should be sent to FRP@caiso.com.

APPENDIX A: NOMENCLATURE

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

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

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

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

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

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

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

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

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

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

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

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

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

UU the set of upward uncertainty sources

UD the set of downward uncertainty sources

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

λ_t^{FRU} shadow price of upward flexible ramping constraint at time interval t

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

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

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

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

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

α regulation ramp sharing coefficient

β spinning reserve ramp sharing coefficient

γ flexible ramping product ramp sharing coefficient

η non-spinning reserve ramp sharing coefficient