Flexible Ramping Products

Revised Straw Proposal

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Straw Proposal – Flexible Ramping Products

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1. INTRODUCTION

This paper will describe the ISO's proposal to define the upward and downward flexible ramping products. The purpose of this stakeholder effort is to develop market-based flexible ramping products to address the operational needs in real-time market facing the upcoming challenges from increasing renewable penetration. Prior to these market-based full flexible ramping products, the ISO has proposed to implement a flexible ramping constraint to address certain reliability and operational issues observed in the ISO's operation of the grid.[1] Upon the completion of the Flexible Ramping Constraint stakeholder process, the ISO recognized that greater market effectiveness can be gained by developing market-based products that allow for the identification, commoditization and compensation for the needed flexible capability. The ISO has observed that the unit commitment 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. For example, the insufficient ramping capability sometimes manifests itself in triggering power balance violations, which means the there is no feasible system wide RTD schedule to maintain supply and demand power balance. In this case, the system has to rely on regulation services to resolve the issue in real delivery time after the imbalance has caused frequency deviation or area control error (ACE), which is undesirable outcome. If there is insufficient regulation service, the result of insufficient ramping capability may result in leaning on interconnection. In addition, when power balance is violated, the RTD energy price is not priced by economic bids, but by administrative penalty prices, which may impact market efficiency in the long run.

The flexible ramping products to be developed in this stakeholder process will help the system to maintain healthy ramping capability. The flexible ramping products specifically target the imbalance differences that arise between the RTPD and RTD, which are 5-minute variability and uncertainties from the RTPD point of view. The term "variability and uncertainties" is used in the

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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

ISO's 20% renewable portfolio standard study in the context of load following requirements.[2] Specifically, the variability may come from market granularity differences in load profile, variable energy resource supply. In addition variability may also arise due to unit startup/shut down profile, multi-stage generator transition profile, and inter-tie schedule inter-hour ramping profile. The uncertainties may include everything that has a random nature, such as load forecast error, variable energy resources' forecast error, and other uninstructed deviations. We use the same term to make connections with the ISO's previous study from a conceptual level, and will clarify the differences between flexible ramping products and load following later in the proposal. The 5-minute variability and uncertainties are realized in the RTD, and the RTD will economically dispatch resources including deploying procured flexible ramping capabilities accordingly. Market participants will be allowed to offer ramping capabilities into the market, and the ISO will optimize such offers to economically meet the anticipated 5-minute variability and uncertainties. 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 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, inadvertent transfers between other balancing authority areas or Area Control Error (ACE), and will trigger the utilization of automatic generation control on resources that are awarded regulation services in day-ahead for the corresponding hour or in 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

[2] CAISO, Integration of Renewable Resources, http://www.caiso.com/2804/2804d036401f0.pdf

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 not be sufficient to maintain power balance in RTD, a reliability concern. In order to operate the grid reliably, the ISO proposes to define the flexible ramping products, which provides a market mechanism for procuring sufficient ramping capability to handle certain variability and uncertainties.

As illustrated in Figure 1, variability and uncertainties are classified into two categories according to the time they are realized. The market clearing granularity difference between RTPD and RTD results in 5-minute variability to be realized in RTD. In addition, certain uncertainties are also realized after RTPD and before RTD. These post RTPD uncertainties include load forecast changes, variable energy resources production changes, uninstructed deviations, and forced outages. The post RTPD variability and uncertainties are realized before the RTD dispatches, so RTD dispatches can "recourse"[3] according to the realizations. Approaching actual delivery time after the RTD run, the difference between actual supply/demand outputs and RTD supply/demand schedules results in post RTD variability and uncertainties. This real-time variability is caused by using the 5-minute granularity in RTD to approximate continuous output in real-time. These post RTD uncertainties include deviations of actual load from RTD load forecast, uninstructed deviations, small outages which happen in real-time, and so on. Because RTD is the last opportunity for sending out dispatches under normal operating conditions, the post RTD uncertainties once realized will only be handled by automatic generation controls (AGC), which are procured in day-ahead or corresponding RTPD as regulation services. The difference between the two categories of variability and uncertainties and how to address them are illustrated in Figure 2.

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

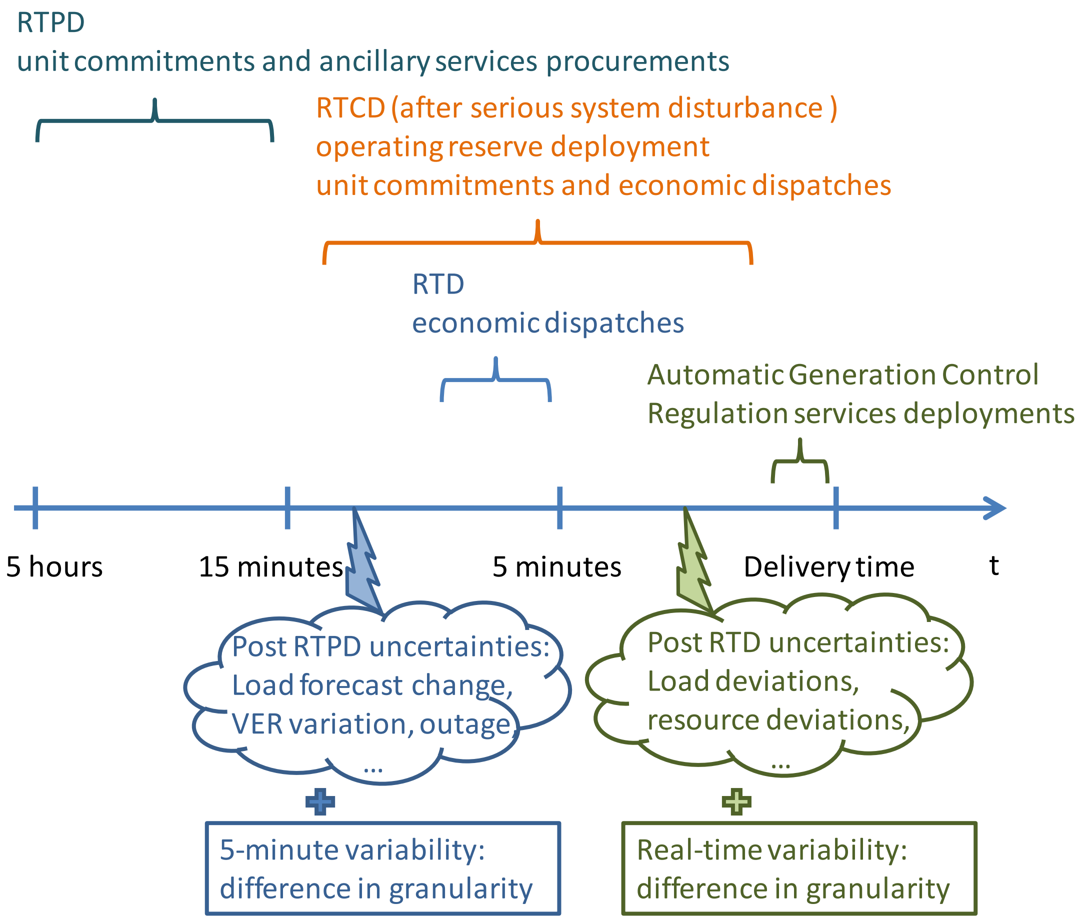

FIGURE 1: REAL-TIME MARKETS TIME FRAME

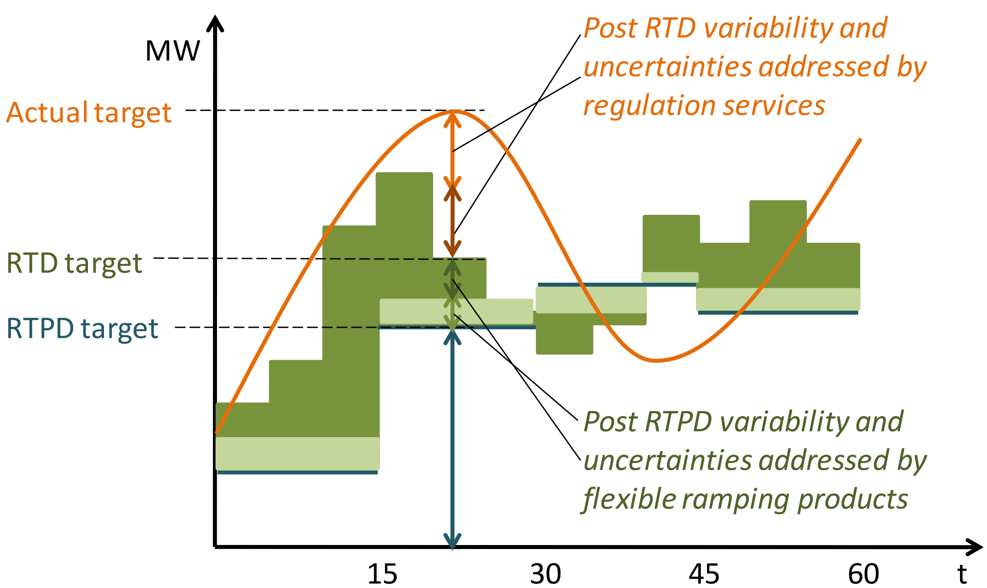

FIGURE 2: HANDLING VARIABILITY AND UNCERTAINTIES WITH FLEXIBLE RAMPING PRODUCTS AND REGULATION SERVICES

The objective of the flexible ramp product is to ensure sufficient flexibility is committed in RTPD with high confidence anticipating imbalance differences can be realized in RTD. Such differences can arise due to load and supply variability and uncertainties. Variability can be expressed as the difference between hourly (load following) or 15 minute (flexible ramp) average net load and 5 minute average net load. Uncertainties can be expressed as the differences expected net load and the expected net load plus forecast error. Flexible ramping product is similar to load following referred to in renewable integration planning studies except that the load following variability component is based on the difference between hourly average net load and the 5 minute average net load levels accounting for uncertainties while the flexible ramp product variability component is based on the difference between 15 minute average net load and 5 minute average net load. In an operational timeframe that has a 15-minute unit commitment process such as RTPD, it is appropriate to consider the flexible ramp product quantifying the difference between net load in RTPD 15-minute interval and the 5-minute interval. For a particular interval, the difference between load following requirement and flexible ramp requirement is addressed by the RTPD commitment. The following conceptual relationships attempt to illustrate the relationship of load following and flexible ramp product and their associated contributions.

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

where

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

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

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

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

and

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

where

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

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

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

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

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

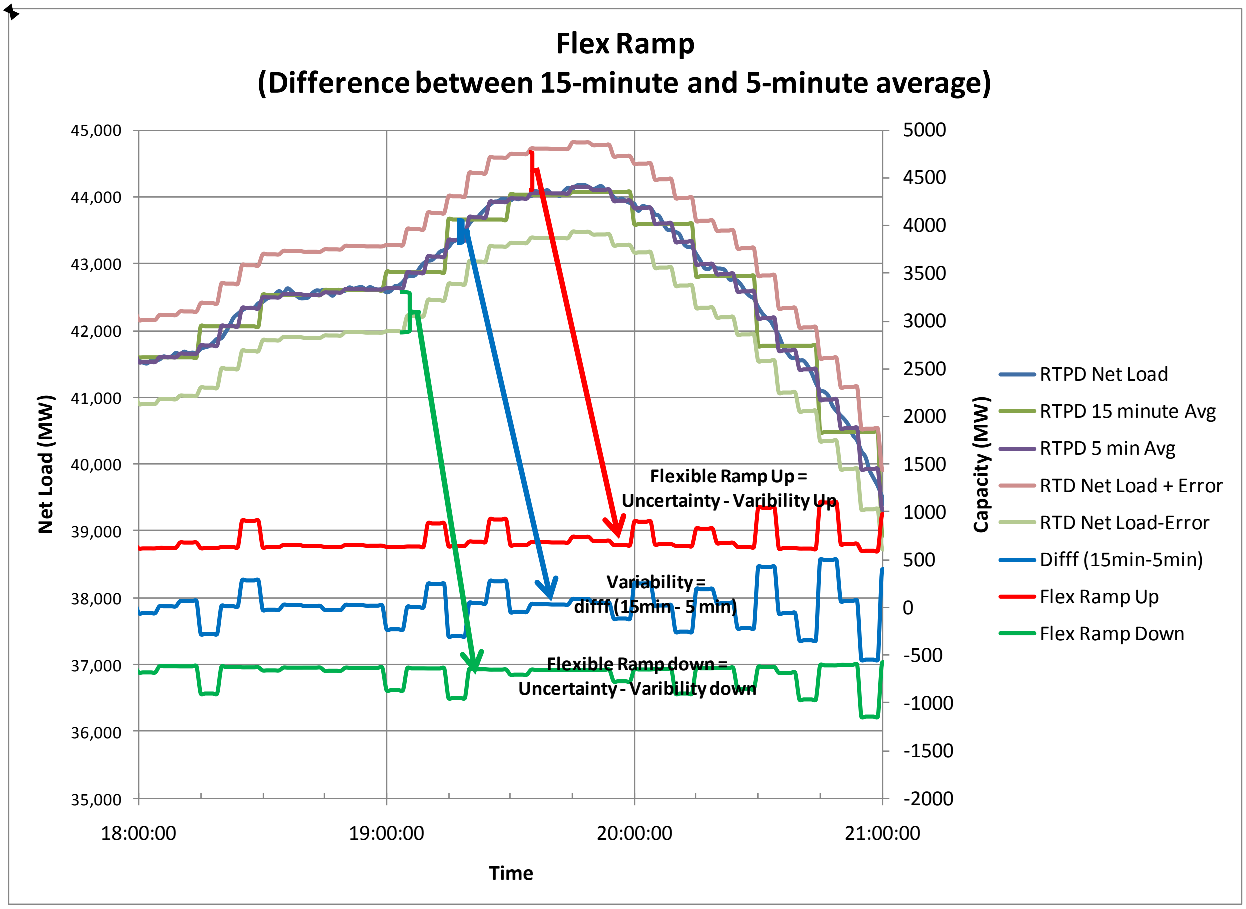

Figure 3a: Flexible Ramp Product Illustration

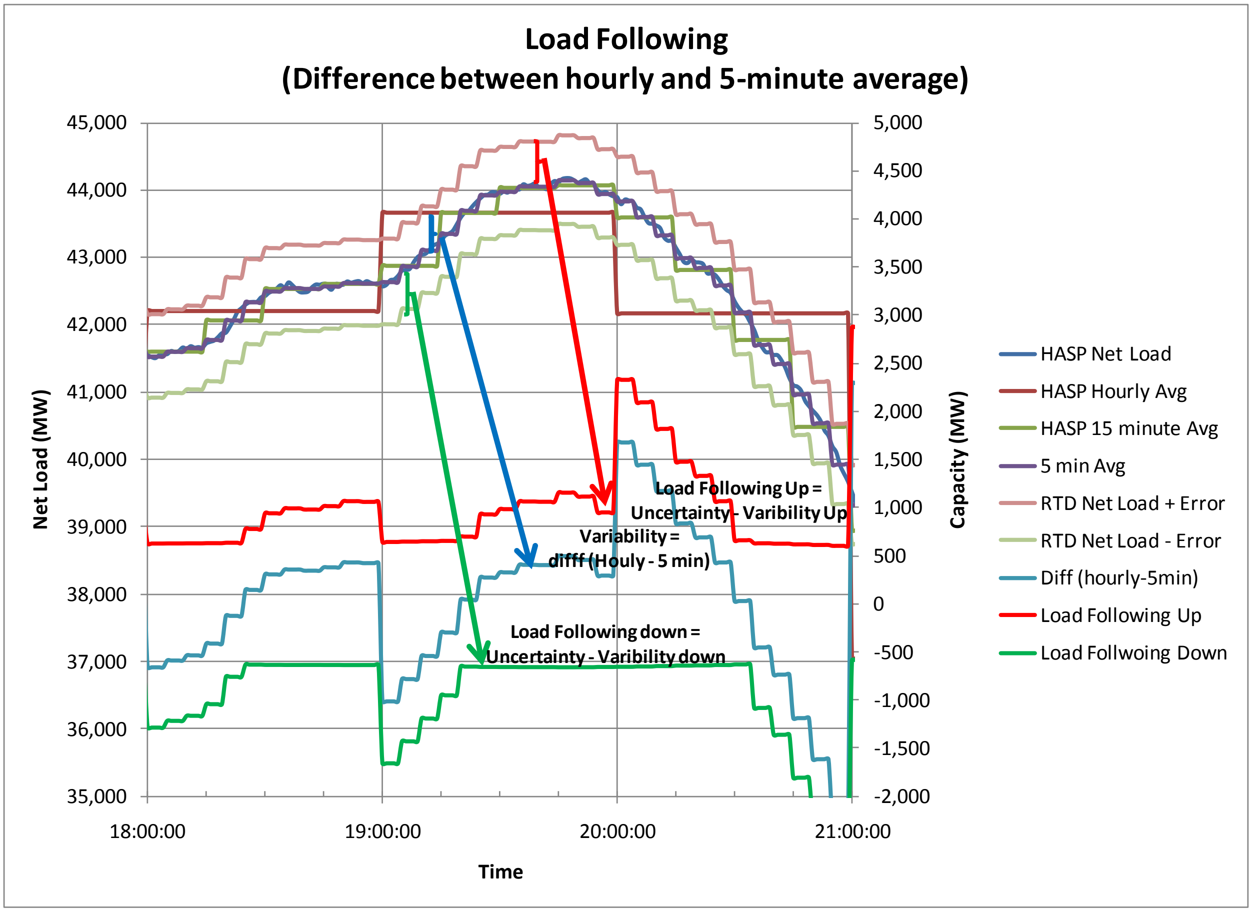

Figure 3b: Load Following Illustration

The flexible ramping products are targeted at handling the post RTPD variability and uncertainties, which is the imbalance difference 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 variability and uncertainties between RTPD and RTD. The ISO will perform statistical study using historical data to determine the requirements. In the day-ahead market, the ISO intends to procure the portion for of flexible ramp that has a high confidence of being used and will procure the remainder of the flexible ramp product in RTPD. One approach is to procure in the day-ahead market a quantity portion of the flexible ramp product that represents the minimum amount of flexible ramp required for an hour. Another approach is to procure to a certain confidence interval in the day-ahead (e.g. 60% confidence) and procure any additional flexible ramp product to achieve a higher confidence interval (e.g. 95% confidence) in RTPD.

This revised straw proposal will provides more procurement and allocation details and attempts to responds to stakeholder questions and feedback. Important additions and revisions from the straw proposal include:

- clarification of terminology about variability and uncertainties
- flexible ramping product requirements

- connection between flexible ramping products and load following requirements
- interplay of day-ahead market and RTPD in terms of conversions between non-contingent spinning reserve and upward flexible ramping products in RTPD
- revision of the third RTD interval deployment method
- clarification of flexible ramping product settlement
- more intuitive examples
- cost allocation method

2. FLEXIBLE RAMPING PRODUCTS DESIGN

The flexible ramping products are designed to deal with the imbalance differences between the RTPD and the RTD. The differences can result from variability or uncertainties. From a stochastic programming point of view, faced with the variability and uncertainties, a stochastic program will commit and dispatch units differently than without those variability and uncertainties considered, such as committing more flexible units, positioning units at faster ramping dispatch levels in anticipation of imbalance changes in RTD. The current technology does not allow detailed modeling of those variability and uncertainties and solving stochastic programs in real-time. Therefore, the flexible ramping products are created as a heuristic way to mimic what a stochastic program would do to deal with those variability and uncertainties. In other words, the flexible ramping products will be able to commit fast ramping units, and position units at fast ramping dispatch levels. 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 dispatches, will also receive RTD energy payments.

Because RTD is on a 5-minute interval basis, the flexible ramping products are also a 5-minute ramping products[4] meaning that the flexible ramping product award is limited by how much a resource can ramp within 5 minutes. This is to ensure that the procured flexible ramping 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 submit bids offering the flexible ramping product. Also, resources that submit flexible ramping product 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 DAY-AHEAD AND RTPD

This section will cover the stylized optimization model of co-optimizing the flexible ramping products with energy and ancillary services in both day-ahead market and RTPD. The interplay between day-ahead market and RTPD will be discussed in section 2.2.

The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[5] The meanings of the variables used in this section are explained in Appendix A. We will discuss the changes to the objective function and constraints on top of Wu and Rothleder's model due to the addition of the flexible ramping products. The detailed equations are presented in Appendix B.

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

[5] Tong Wu, Mark Rothleder, Ziad Alaywan, and Alex D. Papalexopoulos, "Pricing Energy and Ancillary Services in Integrated Market Systems by an Optimal Power Flow," *IEEE Transactions on Power Systems*, pp.339-347, 2004.

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

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

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

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

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

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

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

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

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

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

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

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

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

Nominal charge could conceptually be associated with variability or uncertainty *u* that incurs flexible ramping need is $\lambda_t^{FRU} \cdot R_{u,t}^{FRU}$, and the total charge is $\lambda_t^{FRU} \cdot \sum_{u \in UU} R_{u,t}^{FRU}$. Note that the charge on variability or uncertainty *u* is a nominal charge meaning *u* would have to pay the charge under perfect cost causation scheme. It is not the real settlement charge under the current ISO's proposal, but serves the purpose of providing an economic signal to indicate that variability or uncertainty *u* should bear the flexible ramping cost. The proposed settlement charge will be discussed later in the cost allocation section.

If there is no flexible ramping scarcity, the complementary slackness holds at the optimal solution

$$\lambda_t^{FRU} \cdot \left(\sum_{u \in UU} R_{u,t}^{FRU} - \sum_{i \in I_{FR}} FRU_{i,t} \right) = 0$$

This means the ISO should be revenue neutral under normal conditions.

If there is flexible ramping scarcity of $SLK_t^{FRU} = \sum_{u \in UU} R_{u,t}^{FRU} - \sum_{i \in I_{FR}} FRU_{i,t} > 0$, then

$$\lambda_t^{FRU} \cdot \left(\sum_{u \in UU} R_{u,t}^{FRU} - \sum_{i \in I_{FR}} FRU_{i,t} \right) = \lambda_t^{FRU} \cdot SLK_t^{FRU} > 0$$

This means the ISO is revenue adequate.

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

2.2 INTERPLAY BETWEEN DAY-AHEAD MARKET AND RTPD

Currently, the ancillary services procured in day-ahead market will be protected similar to self-provision in real-time market. Similarly, the flexible ramping products procured in day-ahead will also be protected in RTPD. In addition, the day-ahead non-contingent reserve awards may be fully or partially converted to upward flexible ramping if the resources have economic energy bids in RTPD. The day-ahead non-contingent reserve awards are from resources who flag them as non-contingent meaning that they are willing to be dispatched for energy rather than be kept as operating reserve if condition permits. Therefore, allowing them to be converted to flexible ramping product and then potentially be dispatched to meet realized imbalance difference is consistent with their intention. On the other hand, upward flexible ramping awards may also be fully or partially converted to contingent spinning reserves if the resources are qualified to provide spinning reserve. The potential conversions are summarized in Figure 3. The non-contingent non-spinning reserve awards in day-ahead that become online in RTPD are treated the same as non-contingent spinning reserve awards, and are allowed to be fully or partially converted to contingent spinning reserve or upward flexible ramping product.

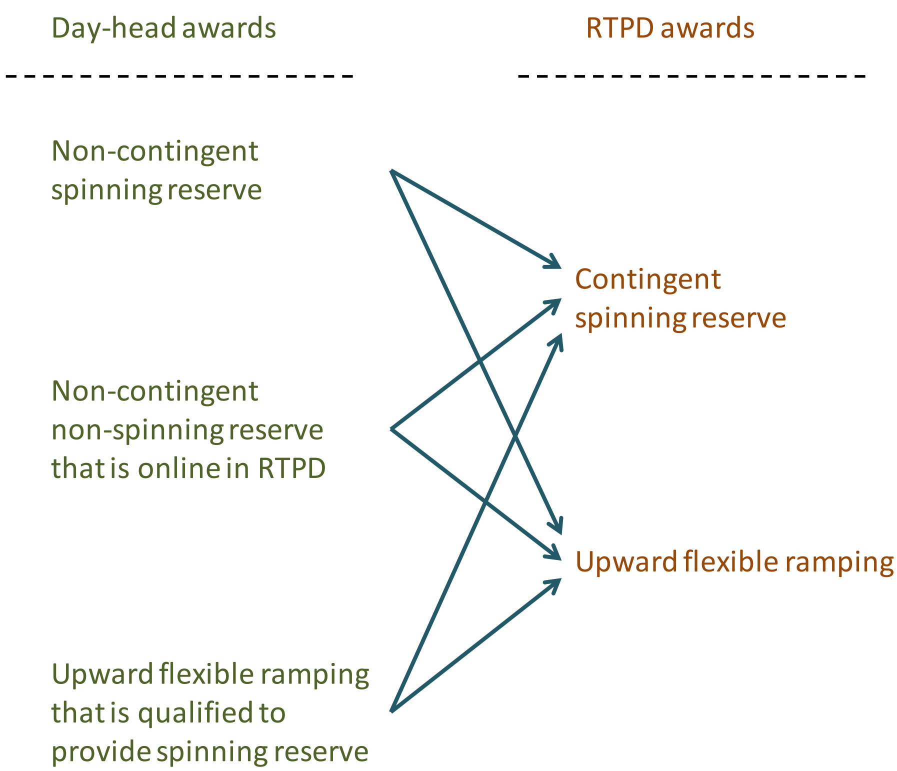


FIGURE 3: CONVERSIONS BETWEEN NON-CONTINGENT RESERVES AND UPWARD FLEXIBLE RAMPING PRODUCT

Allowing non-contingent reserves to be converted to upward flexible ramping product helps deal with ramping scarcity, and allowing upward flexible ramping product to be converted to spinning reserve helps deal with operating reserve scarcity. These conversions will increase the dispatch flexibility and market efficiency by allowing flexible resources to be used in the most valuable way.

The conversion will only happen in the direction of lower value to higher value. For example, non-contingent spinning reserve can be converted to upward flexible ramping product only when the marginal price of upward flexible ramping is higher than or equal to the marginal price of spinning reserve in RTPD. This can be proved by contradiction. Assume the marginal price of spinning reserve is higher than the upward flexible ramping product, and at least one resource's non-contingent spinning reserve is converted to upward flexible ramping product. In this case, if the conversion is reduced by 1 MW, then the change to the objective function value is equal to the marginal price of upward flexible ramping product minus the marginal price of spinning reserve, which is negative by assumption. This means the objective function value can be improved (reduced) by reversing the conversion, and thus contradicts the optimality of the conversion. Therefore, the conversion should not have taken place. This completes the proof. Conversion from flexible ramping to spinning reserve can be proved in the same way. This also implies that the conversion can only take place in one direction for the same ancillary service region.

The ISO also allows substitution of higher quality ancillary service for lower quality ancillary service, such regulation-up for spinning reserve, and spinning reserve for non-spinning reserve. The key difference between the ancillary service substitution and the flexible ramping conversion are

- the ancillary service substitution is always the full amount, while the flexible ramping can be partially converted,
- the ancillary services have a predetermined order of quality, but flexible ramping conversion cannot be predetermined based on higher quality or lower quality than spinning reserve and any other ancillary service,
- the order of ancillary service marginal prices is consistent with the quality order for ancillary services, while the flexible ramping marginal price does not have a predetermined relationship with the ancillary service marginal prices; the direction of conversion must be consistent with the marginal price relationship determined in the optimization.

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

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

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

The upward flexible ramping portion $FRU_{i,t}$ will be used to meet the upward flexible ramping requirement in RTPD, and the spinning reserve portion $SP_{i,t}$ will be used to meet the spinning reserve requirement (cascading with regulation-up and non-spinning reserve) in RTPD. Note that the upward flexible ramping portion $FRU_{i,t}$ still needs to satisfy the 5-minute ramping capability limit.

The unchanged portion of the spinning reserve or upward flexible ramping product, i.e. the amount of day-ahead procured spinning reserve that stays as spinning reserve in RTPD and the amount of day-ahead procured upward flexible ramping product that stays as upward flexible ramping in RTPD, has been paid in day-ahead and will not be paid in RTPD.

The amount of day-ahead procured non-contingent spinning reserve that becomes upward flexible ramping product in RTPD will be paid in day-ahead market at the day-ahead spinning reserve marginal price, will be paid in RTPD at the difference between the flexible ramping marginal price and the spinning reserve marginal price, i.e. RTPD upward flexible ramping marginal price – RTPD spinning reserve marginal price, which has been proved to be non-negative.

The amount of day-ahead procured upward flexible ramping that becomes spinning reserve in RTPD will be paid in day-ahead market at the day-ahead upward flexible ramping marginal price, and will be paid in RTPD at the difference between the spinning reserve marginal price and the flexible ramping marginal price, i.e. RTPD spinning reserve marginal price – RTPD upward flexible ramping marginal price, which has been proved to be non-negative.

Another type of interplay between day-ahead and RTPD is about the energy bids considered when procuring flexible ramp in the day-ahead. If flexible ramping products are procured in day-ahead, they are protected like self-provisions in RTPD. In this case, should their day-ahead energy bids be locked up in real-time markets? Without such a mechanism, there may exist undesirable opportunity in real-time markets to re-bid high energy bids. This issue needs further consideration in the stakeholder process.

2.3 DEPLOYING FLEXIBLE RAMPING IN RTD

In RTD, imbalance differences 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 creates an issue. That is, RTD energy price is influenced by the penalty price. 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 imbalance differences. The realized imbalance differences can result from any supply or demand differences expected in a 15 minute RTPD interval and any respective 5 minute RTD rather than a limited subset of differences. Therefore, after the differences are realized in RTD, the maximum needed deployment from the flexible ramping product is the total amount of realized imbalance differences. In other words, flexible ramping equal to the amount of realized imbalance differences should be released (made available) for dispatch in RTD. 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 imbalance differences, which can be modeled as the following constraints:

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

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

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

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

The remaining flexible ramping that was procured within the 15 minute RTPD interval but not dispatched for energy in one of the respective 5 minute RTD interval is what is available for the next RTD interval to use. Note that the remaining flexible ramping products are still variables to be determined in the RTD dispatch, while the deployed flexible ramping products will be rolled into the energy dispatches. In addition, we clarify the following terminologies:

- "Dispatched" means dispatched for energy. As long as the resource has an energy bid, it can possibly be dispatched for energy, and it does not matter if the resource carries flexible ramping awards or not. This term is a resource specific.
- "Released" means portion of the system wide flexible ramping products is made available for dispatch. The released amount is equal to the total realized imbalance difference. This term is system wide, not resource specific.
- "Deployed" means after releasing the system wide amount, portion of a resource's flexible ramping awards is converted into energy. In this case, the resource's remaining flexible ramping capability is less than its flexible ramping award, i.e. deployed. It is also possible that a resource that carries flexible ramping awards is dispatched for energy without deploying its flexible ramping awards. In this case, the resource's remaining flexible ramping capacity is equal to its award. This can happen when a resource's capacity is not binding, so that it can be dispatched for energy, and at the same time maintaining the flexible ramping awards. This will be demonstrated in section 3.4 example 1.

Several stakeholders requested the ISO to clarify how the flexible ramp capability will be deployed. Furthermore, some stakeholders suggested that it was unnecessary to hold flexible ramp capability from being deployed in the third 5-minute interval for which the flexible ramp was procured in RTPD. As a result of this feedback, the ISO now clarifies the flexible ramp deployment method in RTD. There are several important properties in the ISO's proposed deployment method. These constraints will only be enforced in the first and the second RTD runs, but not the third RTD run. In the first and second RTD runs, there are still future imbalance differences not realized yet, and that is why the deployment needs to be restricted by these constraints so that there are remain ramping capability to meet future imbalance differences. However, in the third RTD interval, the imbalance differences have been fully realized for the 15-minute RTPD procurement interval, so there is no need to explicitly restrict the deployment in the last 5-minute interval. Nevertheless, the deployment may be implicitly restricted by the next RTPD interval flexible ramping awards. In other words, the procured flexible ramping products are available for dispatching in the third RTD interval to the extent that it does not prevent the resource from fulfilling its flexible ramping awards in the next RTPD.

Compared with the penalty price approach, the deployment method in the proposal has several advantages.

1) There is no economic withholding effect of the flexible ramping. RTD energy price will be determined by true market bids without introducing penalty prices for flexible ramping products.

2) When the realized imbalance differences requires flexible ramping awards but in reduced amount, the constraints that limit the deployment will force the system to recover previously used flexible ramping capabilities instead of deploying flexible ramping award in the opposite direction. This feature helps to maintain the flexible ramping capability on a continuous basis.

2.4 SETTLEMENT OF FLEXIBLE RAMPING PRODUCTS

Stakeholders have requested additional detail regarding how the ISO will settle and ensure compliance with awarded flexible ramping product service. In response the ISO proposes the following additional detail of settlement of flexible ramping products in previous sections. This section will summarize them, and also briefly discuss the no-pay rules.

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

- Day-ahead procured flexible ramping products will be settled at the day-ahead flexible ramping prices.
- RTPD procured incremental flexible ramping products will be settled at RTPD flexible ramping prices.
- Day-ahead non-contingent spinning reserve award that is converted to upward flexible ramping in RTPD will receive the difference between the RTPD upward flexible ramping price and the RTPD spinning reserve price for the converted amount.
- Day-ahead upward flexible ramping award that is converted to spinning reserve in RTPD will receive the difference between the RTPD spinning reserve price and the RTPD upward flexible ramping price for the converted amount.
- RTD deployed amount of flexible ramping will be settled at RTD energy price.

When the flexible ramping products are procured in RTPD, the marginal prices may already include the opportunity cost of not providing energy to meet RTPD target if the resource's capacity is binding. The opportunity cost should be paid because the resource will indeed lose the opportunity to meet the RTPD expected target by deploying the flexible ramping awards in RTD dispatch when there is no realized differences between RTPD and RTD. This is guaranteed by the constraint which limits the deployed flexible ramping to the amount of realized imbalance differences, which is what is beyond the RTPD target. To see this clearly, if there is no realized imbalance differences, then the flexible ramping awards will not be deployed, and because the flexible ramping capability is held back from energy dispatch, it should get the energy opportunity cost in the flexible ramping price. The flexible ramping price, which includes the energy opportunity cost of unable to provide RTPD energy, should not void the energy payment in RTD if the flexible ramping is deployed to meet the realized imbalance difference beyond the RTPD energy target.

Resources awarded flexible ramping up and flexible ramping down will be subject to no pay if the resource is unable to be considered in RTD dispatch or does not respond fully to RTD dispatch.

For each Settlement Interval in which a resource fails to maintain sufficient ramp available to RTD from flexible ramping capacity or has available only a portion of the expected ramp capability, the capacity payment will be reduced to the extent of the deficiency.

For each Settlement Interval in which a resource fails to supply Energy from flexible ramping up capacity in accordance with a Dispatch Instruction, or supplies only a portion of the Energy specified in the Dispatch Instruction, the capacity payment will be reduced to the extent of the deficiency.

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,
- downward flexible ramping product requirement is 8 MW.

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,
- $\gamma = 1.0$, which means ramp sharing between flexible ramping product and energy is not allowed,
- $\eta = 0$, which means ramp sharing between non-spinning reserve and energy is allowed.

The bids and generator parameters are listed in Table 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	2.5	2	0	0	3	3	190	0	10	5	0	0	8
G2	35	2.8	2.2	0	0	2	2	90	0	0	5	0	0	0
G3	50	1.5	1	0	0	1	1	10	10	0	10	0	20	0

EN – energy RU – regulation up RD – regulation down SP – spinning reserve
NS – non-spinning reserve FRU – flexible ramping up FRD – flexible ramping down

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 LIMITS 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, and the corresponding marginal prices are listed in Table 4.

gen	Energy schedule	Reg Up schedule	Reg down schedule	Spin schedule	Non-spin schedule	Flex ramp up schedule	Flex ramp down schedule
G1	195	0	10	5	0	0	3
G2	95	0	0	5	0	5	5
G3	10	10	0	15	0	15	0

TABLE 3: OPTIMAL SCHEDULES

Product	Price ($/MWh)
Energy	35
Regulation-up	6.5
Regulation-down	2
Spinning reserve	5
Non-spinning reserve	0
Upward flexible ramping product	6
Downward flexible ramping product	3

TABLE 4: MARGINAL PRICES

To verify the upward flexible ramping product marginal price $6/MWh, increasing upward flexible ramping requirement by 1 MW, the revised optimal schedules will be

gen	Energy schedule	Reg Up schedule	Reg down schedule	Spin schedule	Non-spin schedule	Flex ramp up schedule	Flex ramp down schedule
G1	194	0	10	6	0	0	3
G2	96	0	0	5	0	5	5
G3	10	10	0	14	0	16	0

TABLE 5: OPTIMAL SCHEDULES WITH UPWARD FLEXIBLE RAMPING REQUIREMENT INCREASED BY 1 MW

The incremental costs due to the changed schedule in Table 4 are listed in Table 6, and the total incremental cost is $6/MWh. Because the flexible ramping products are linked with energy schedules and ancillary services through co-optimization, the marginal prices will reflect all opportunity costs. That is why in this example the upward flexible ramping product price is higher than the highest upward flexible ramping bid price in the system.

gen	En cost (price*MW)	RU cost (price*MW)	RD cost (price*MW)	SP cost (price*MW)	NS cost (price*MW)	FRU cost (price*MW)	FRD cost (price*MW)
G1	−30*1	0	0	+0*1	0	0	0
G2	+35*1	0	0	0	0	0	0
G3	0	0	0	−0*1	0	+1*1	0

TABLE 6: INCREMENTAL COST WITH UPWARD FLEXIBLE RAMPING REQUIREMENT INCREASED BY 1 MW

To verify the downward flexible ramping product marginal price $3/MWh, increasing downward flexible ramping requirement by 1 MW, the revised optimal schedules will be

gen	Energy schedule	Reg Up schedule	Reg down schedule	Spin schedule	Non-spin schedule	Flex ramp up schedule	Flex ramp down schedule
G1	195	0	10	5	0	0	4
G2	95	0	0	5	0	5	5
G3	10	10	0	15	0	15	0

TABLE 7: OPTIMAL SCHEDULES WITH DOWNWARD FLEXIBLE RAMPING REQUIREMENT INCREASED BY 1 MW

The incremental costs due to the changed schedule in Table 7 are listed in Table 8, and the total incremental cost is $3/MWh. In this case, the downward flexible ramping price is directly set by G1's bid reflecting zero opportunity cost.

gen	En cost (price*MW)	RU cost (price*MW)	RD cost (price*MW)	SP cost (price*MW)	NS cost (price*MW)	FRU cost (price*MW)	FRD cost (price*MW)
G1	0	0	0	0	0	0	+3*1
G2	0	0	0	0	0	0	0
G3	0	0	0	0	0	0	0

TABLE 8: INCREMENTAL COST WITH DWONWARD FLEXIBLE RAMPING REQUIREMENT INCREASED BY 1 MW

Now slightly change the example by adding another generator G4 , which has 6 MW non-contingent spinning reserve award in day-ahead. G4's operational ramp rate is 1 MW/minute. As discussed in section 2.2 Interplay between day-ahead market and RTPD, this 6 MW of non-contingent spinning reserve may be converted to upward flexible ramping product if upward flexible ramping is more valuable than spinning reserve. As shown in Table 4, upward flexible ramping marginal price is $6/MWh, while spinning reserve marginal price is $5/MWh. Therefore, it is economic to convert G4's non-contingent reserve into upward flexible ramping product. The optimal schedules are listed in Table 9. As expected, 5 MW from G4's day-ahead award is converted into upward flexible ramping, and 1 MW remains as spinning reserve. This is because G4 has 1 MW/minute ramp rate, and thus can only provide 5 MW flexible ramping. The product prices will also change with G4 being added, which are listed in Table 10. Note that spinning reserve price drops to $0/MWh, and upward flexible ramping product price drops to $1/MWh because of the non-contingent spinning reserve provision from G4.

gen	Energy schedule	Reg Up schedule	Reg down schedule	Spin schedule	Non-spin schedule	Flex ramp up schedule	Flex ramp down schedule
G1	200	0	10	0	0	0	3
G2	90	0	0	5	0	5	5
G3	10	10	0	19	0	10	0
G4	0	0	0	1	0	5	0

TABLE 9: OPTIMAL SCHEDULES WITH G4 ADDED

Product	Price ($/MWh)
Energy	35
Regulation-up	1.5
Regulation-down	2

Spinning reserve	0
Non-spinning reserve	0
Upward flexible ramping product	1
Downward flexible ramping product	3

TABLE 10: PRODUCT PRICES WITH G4 ADDED

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 (price*MW)
G1	0	8	15/60*(6*0+3*3) = $2.25
G2	0	0	15/60*(6*5+3*5) = $11.25
G3	20	0	15/60*(6*15+3*0) = $22.5
total	20	8	15/60*(6*20+3*8) = $36

3.4 DEPLOYING FLEXIBLE RAMPING PRODUCTS IN RTD

EXAMPLE 1 FLEXIBLE RAMPING PRODUCTS DEPLOYED IN RESPONSE TO REALIZED IMBALANCE DIFFERENCES

This example will illustrate how to deploy procured flexible ramping products in response to realized imbalance difference in RTD. For simplicity, neglect ancillary services. The data used in the example is listed in Table 11. First, consider upward flexible ramping deployment. The RTD clearing results as the realized imbalance differences requiring upward ramping varies are plotted in Figure 4.

gen	En	Pmin	Pmax	Initial	Ramp	RTPD upward	RTPD downward

	bid			MW	rate	flex ramp award	flex ramp award
G1	35	40	100	50	2	0	10
G2	45	40	100	40	8	40	0
G3	55	20	100	50	10	50	30

TABLE 11: AN EXAMPLE OF UPWARD FLEXIBLE RAMPING PRODUCT DEPLOYMENT

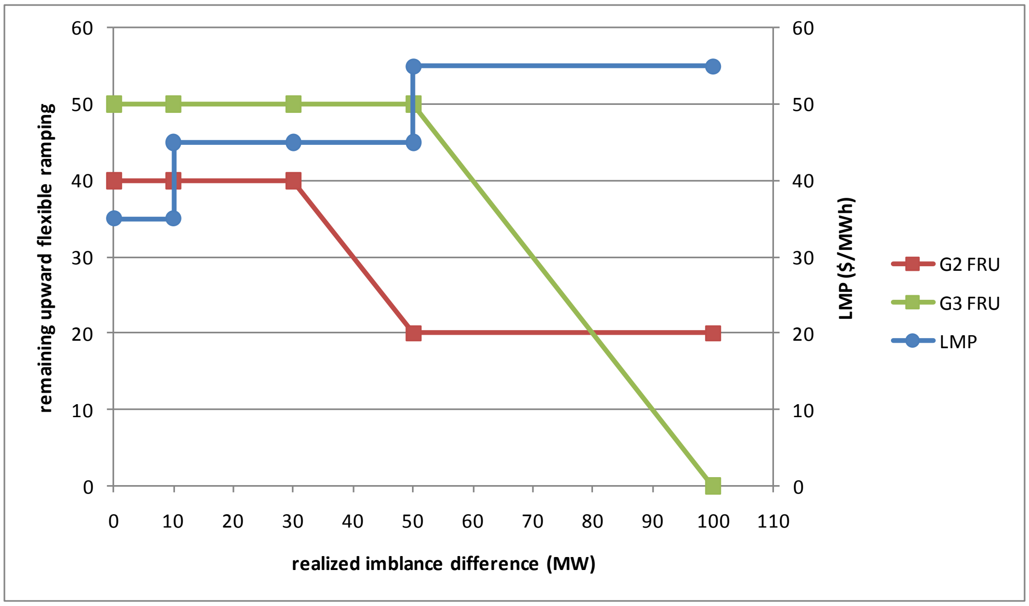


FIGURE 4: MARKET CLEARING RESULTS V.S. REALIZED UPWARD IMBALANCE DIFFERENCE

The curves shown in Figure 4 are explained segment-wise as follows.

1. Realized upward imbalance difference between 0 MW and 10 MW

   The cheapest resource G1 will be dispatched. LMP is set by G1's bid $35/MWh.

2. Realized upward uncertainty MW between 10 MW and 30 MW

   G1's ramping rate is 2 MW/minute, so it can be dispatched up in 5 minutes for at most 10MW. The next cheapest resource G2 will need to be dispatched for energy to cover realized imbalance difference beyond 10 MW. LMP is set by G2's bid $45/MWh. Note that G2's upward flexible ramping is not deployed, because G2 is able to support the 40 MW RTPD upward flexible ramping award.

3. Realized upward imbalance difference between 30 MW and 50 MW

   If the realized imbalance difference is more than 30 MW, G2 cannot fully keep its upward flexible ramping because of the generation capacity limitation. Therefore, G2's remaining upward flexible ramping will decrease as the realized imbalance difference amount increases. The LMP is still set by G2's bid $45/MWh. This confirms that the RTD energy price is always set by true economic bids, but not by penalty prices.

4. Realized upward imbalance difference between 50 MW and 100 MW

   G2's upward flexible ramping has been fully deployed. G3's upward flexible ramping is needed for meeting realized imbalance difference greater than 50 MW. Therefore, G3's remaining upward flexible ramping will decrease as the realized imbalance difference amount increases. The LMP is still set by G3's bid $55/MWh.

5. Realized upward imbalance difference greater than 100 MW

   Energy balance will be violated, and LMP goes to penalty price $1000/MWh.

Second, consider downward flexible ramping deployment. The RTD clearing results as the realized imbalance difference requiring downward ramping varies are plotted in Figure 5.

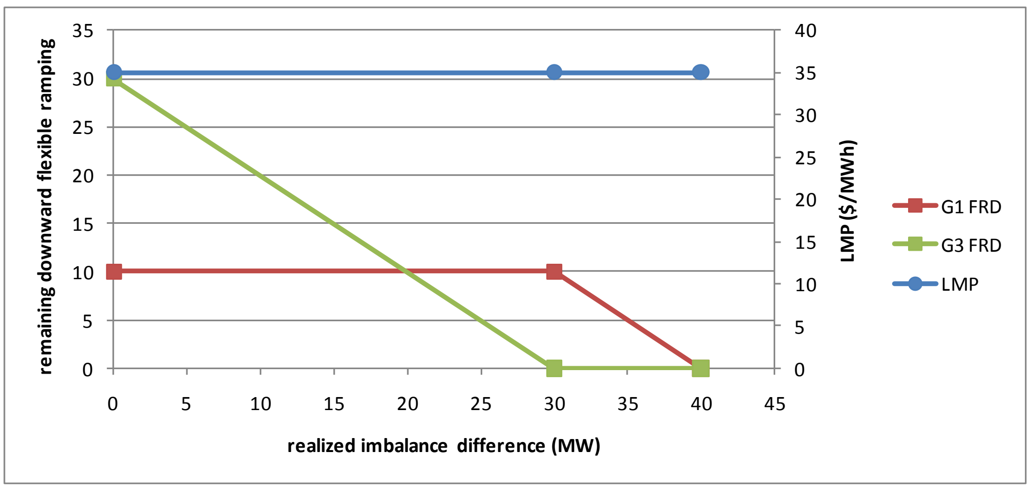


FIGURE 5: MARKET CLEARING RESULTS V.S. REALIZED DOWNWARD IMBALANCE DIFFERENCE

The curves shown in Figure 5 are explained segment-wise as follows.

1. Realized downward imbalance difference between 0 MW and 30 MW

   The most expensive resource G3 will be dispatched down to deploy its downward flexible ramping product. LMP is set by the cheapest resource G1's bid $35/MWh.

   In this scenario, the constraint that restricts the total deployed downward flexible ramping product to the amount of realized imbalance is binding to prevent over-deploying the flexible ramping product. If the constraint is relaxed, the optimal dispatch will reduce G3' output by 2 MW and increase G1's output by 1 MW to meet –1 MW of. The LMP is (–55*2+35*1)/(–1) = $75/MWh. However, this would cause the downward flexible ramping product to be used up more quickly and unnecessarily, which may result in operation issue for later RTD intervals.

2. Realized downward imbalance difference between 30 MW and 40 MW

G3's downward flexible ramping has been fully deployed. Because G2 is at its minimum operating limit, G1's downward flexible ramping has to be deployed to meet the realized downward imbalance difference beyond 30 MW. Again, LMP is set by the cheapest resource G1's bid $35/MWh.

3. Realized downward imbalance difference greater than 40 MW

   Energy balance will be violated, and LMP goes to penalty price –$35/MWh.

There are several important characteristics of the flexible ramping products observed from the example.

- Upward ramping product is only used for realized upward imbalance difference, and downward ramping product is only used for realized downward imbalance difference. Upward and downward flexible ramping products cannot be deployed at the same time.
- RTD dispatches resources in the most economic way to meet RTD energy target, which is equal to the RTPD energy target plus realized imbalance difference. RTD neither models the cost of flexible ramping products, nor prices them.
- Because the rest of the resource fleet that do not carry flexible ramping products can also contribute to the meet the realized imbalance difference, the constraint that limits the amount of deployed flexible ramping to the realized imbalance difference is not restricting in terms of total MW quantities. However, the constraint may be binding in order to prevent the flexible ramping products being over-deployed due to economic reason. In addition, the constraint also helps to recover previously deployed flexible ramping awards if the realized imbalance difference decreases in the current RTD interval compared with the last RTD interval, which will be demonstrated in example 2.
- A resource may be dispatched up to meet the realized imbalance difference, and still keep its upward flexible ramping award when its generation capacity is not binding. The same characteristic also applies to downward flexible ramping product.

EXAMPLE 2 TEMPORAL INTERPLAY

Continue with example 1 without G4. For simplicity, assume a single interval dispatch in RTD, and the generator are all following instructions. Assume the total amount of imbalance difference is realized in the three 5-minute RTD runs in the following way:

Realized total imbalance difference	upward	downward
RTD1	80	0
RTD2	30	0

RTD3	120	0

RTD1:

gen	Energy schedule	Flex ramp up remaining	Flex ramp down remaining
G1	60	0	10
G2	80	20	0
G3	80	20	30

LMP = $55/MWh

The optimal solution in RTD1 is easily verifiable in Figure 4.

RTD2:

gen	Energy schedule	Flex ramp up remaining	Flex ramp down remaining
G1	70	0	10
G2	50	40	0
G3	50	50	30

LMP = $45/MWh

The realized imbalance difference drops to 30 MW in RTD2. The RTD target difference between RTD2 and RTD1 is –50 MW. To meet this change, the most expensive resource G3 will be dispatched down to 50 MW, which is limited its minimum operating limit 20 MW plus its downward flexible ramping award 30 MW. In addition, because G1 is cheaper than G2, it is economic to increase G1's schedule by 10 MW, and decrease G2's schedule by 30 MW. Again, G1's incremental schedule 10 MW is limited by its ramp rate 2 MW/minute. Note that G2's and G3's flexible ramping awards have been fully restored, and will be available for meeting future imbalance difference.

RTD3:

gen	Energy schedule	Flex ramp up remaining	Flex ramp down remaining
G1	80	0	10
G2	90	10	0
G3	90	10	30

LMP = $55/MWh

There is a significant realized imbalance difference increase RTD3. The RTD target difference between RTD3 and RTD2 is 90 MW. G1 is able to provide 10 MW, G2 is able to provide 40 MW, and the rest of 40 MW is provided by G3. G3 can ramp 50 MW in 5 minutes, so it still has capability to meet extra load. Therefore, the LMP is set by G3's bid $55/MWh.

In this example, the constraint that limits the amount of deployed flexible ramping to the realized imbalance difference is binding in RTD2, and force the system to recover previously deployed flexible ramping awards in RTD1. Because the upward flexible ramping capability is recovered in RTD2, the significant need for ramping in RTD3 can be met. This deployment method can effectively maintain the ramping capability.

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 will be implemented for other ancillary services in January 2012.

4.2 FLEXIBLE RAMPING PRODUCT DATA RELEASE

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

5. COST ALLOCATION

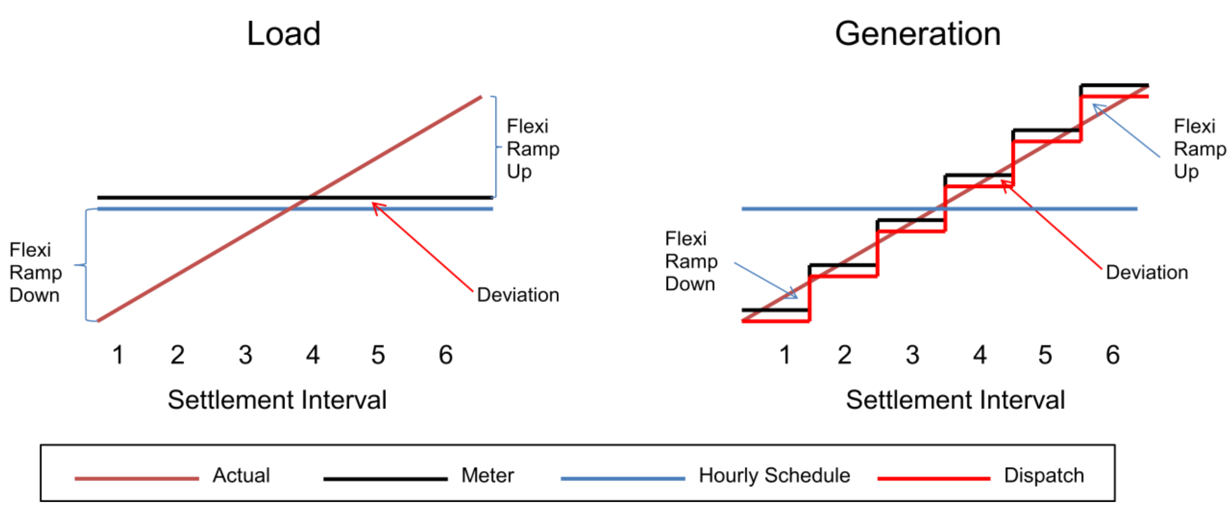
5.1 CHANGES FROM STRAW PROPOSAL

Some stakeholders suggest and the ISO agrees that allocation of reserves and application of cost-causation methodologies require broader review rather than a targeted application with the introduction of the flexible ramp product. As a result the ISO now proposes to clarify and modify the allocation of flexible ramping product. The ISO proposes to allocate cost of the flexible ramping product the same way regulation obligations are allocated or metered demand. The ISO also proposes to maintain transparency regarding the monthly contributors to flexible ramping product. The ISO also proposes to maintain the ability for parties to trade the flexible ramping financial obligations. However, the ISO proposes modify its straw proposal by eliminating allocations of costs attributable to generation resources, imports and export at the end of the month by crediting back costs received from generation resources, imports and exports to load.

5.3 METER AND SCHEDULE GRANULARITY

Since deviations of both load and generation are considered in the procurement target for flexible ramping products, a consistent metering interval would be necessary to implement a single measurement of deviations for both load and generation. However, load is metered hourly and internal generation is metered on a ten minute basis. As illustrated in Figure 6 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 represent the procurement requirements attributable to load deviations and over represent the procurement requirements attributable to generation deviations.

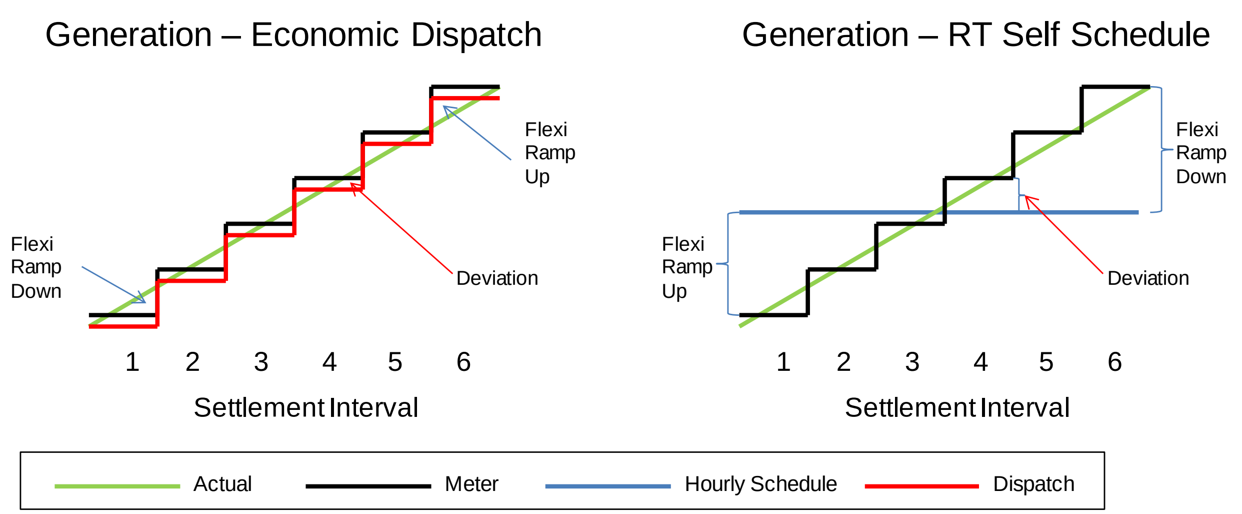
FIGURE 6 - COMPARISON OF LOAD AND GENERATION DEVIATIONS



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 and uncertainties between RTPD and RTD, not the net deviations for an hour. While the five minute meter data could more accurately measure deviations to assess the impact on procurement 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 can drive the procurement of both flexible ramping up and flexible ramping down based upon negative and positive deviations.

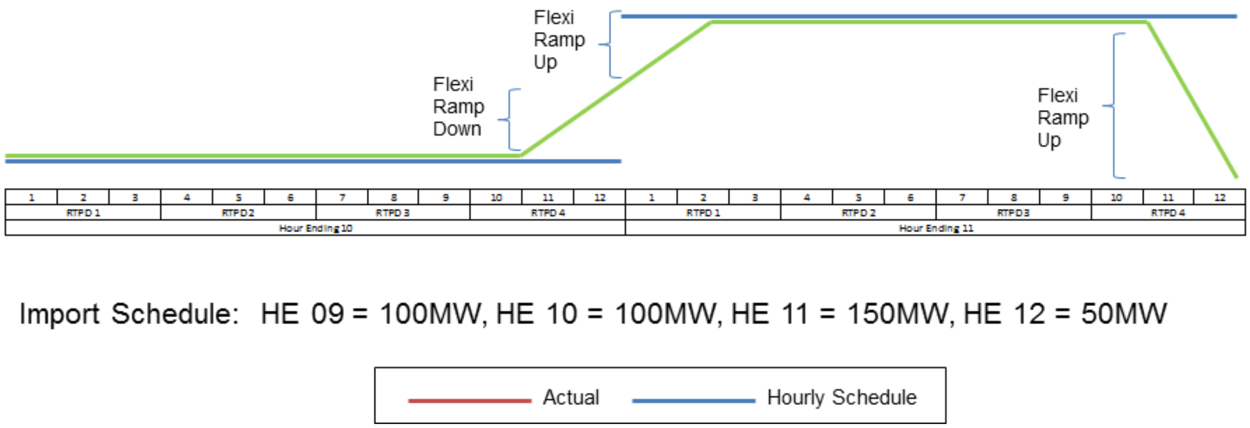
However, when determining the deviations for generation resources, imports and exports it is necessary to further segment the measurement of deviations. The reference point to measure deviations by supply is not aligned for all resources. For resources that respond to five minute dispatch the deviation 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 and exports would be the hourly schedule. Flexible ramping products are not procured for generation which has deviated from its hourly schedule in response to ISO dispatch. As Figure 7 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 7 - COMPARISON OF GENERATION WITH ECONOMIC DISPATCH AND SELF SCHEDULES



An additional segmentation has been added in the revised straw proposal for static intertie hourly schedules. Static hourly schedules for Imports and Exports allow a twenty minute ramp for hourly schedule changes. As shown in Figure 8, when a static hourly import schedule increases, the ISO must have sufficient downward ramping capability for the final two RTD intervals from internal generation to respond to downward dispatches for up to fifty percent of the hourly schedule increase. Then in the subsequent hour, the ISO must have sufficient upward ramping capability for the first two RTD intervals from internal generation able to respond to upward dispatches for up to fifty percent of the hourly schedule increase. The variability and uncertainties surrounding hourly intertie ramps is an additional input in determining the quantity of flexible ramping products.

FIGURE 8 - FLEXIBLE RAMPING REQUIREMENT FROM INTERTIE RAMPS

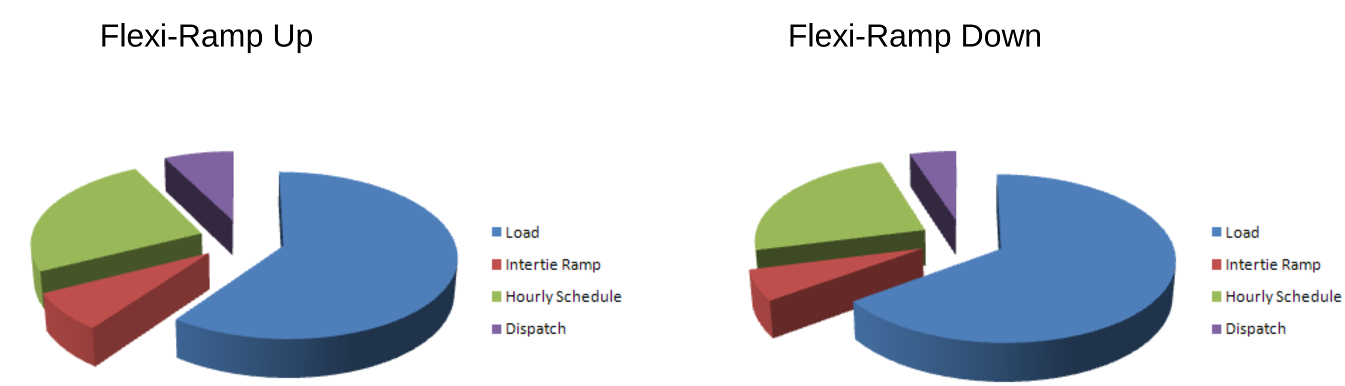


If an intertie schedule does not e-tag its hourly schedule from the HASP, any difference gives rise to deviations that are captured as operational adjustments. The changes in hourly static schedules are similar to deviations from internal generation hourly schedules which can drive a portion the total flexible ramping product costs.

5.4 SETTLEMENT CHARGES TO MEASURE DEVIATIONS

The ISO proposes to create separate cost buckets for flexible ramping up and flexible ramping down. The costs for procuring flexible ramping products in the day-ahead market and real-time market will be combined into a single cost bucket for each direction. This information will be provided to market participants in order to improve transparency of flexible ramping procurement requirements.

FIGURE 9 - COST ALLOCATION PIES AND SLICES



Because of the different reference points to measure deviations, the ISO proposes to further segment the costs in to four slices: (1) costs attributable to load, (2) cost attributable to intertie ramps, (3) costs attributable to deviations from hourly schedules, and (4) costs attributable to deviations from ISO dispatch. Flexible ramping up costs will be driven by negative deviations. Flexible ramping down costs will be driven by positive deviations. Positive and negative deviations will not be netted across settlement intervals in the data released regarding deviations for each slice. 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. The deviations will be calculated by scheduling coordinator for slice 1, slice 2, and operational adjustments for imports/exports. The deviations will be calculated for internal generation and dynamic transfers at a resource level for slices 3 and 4, not aggregated by scheduling coordinator, because the objective is a resource specific assessment of the impact to the flexible ramping procurement target.

The ISO proposes to use existing settlement calculations measure deviations for each of the slices. Table 12 summarizes flexible ramping buckets proposed and the deviation metric to use for providing transparency and tracking sources of imbalance differences between RTPD and RTD.

TABLE 12 - SETTLEMENT CALCULATION FOR COST REPORTING

Pie Slice	Deviation Metric
UP – Load	Regulation Up Ancillary Service (AS) Obligation
UP - Intertie Ramp	Absolute Value Net Hourly Schedule Change of Import & Export, Wheels Exempt
UP – Hourly Schedule	Negative Uninstructed Imbalance Energy 2 Negative Operational Adjustments
UP – Dispatch	Negative Uninstructed Imbalance Energy 1
DOWN – Load	Regulation Down AS Obligation
DOWN – Intertie Ramp	Absolute Value Net Hourly Schedule Change of Import & Export, Wheels Exempt
DOWN – Hourly Schedule	Positive Uninstructed Imbalance Energy 2 Positive Operational Adjustments
DOWN – Dispatch	Positive Uninstructed Imbalance Energy 1

Based upon stakeholder input, the ISO further clarified that load will be allocated based upon regulation AS obligations. This addresses concerns regarding the treatment of load under Metered Subsystems (MSS). The Regulation Up to Load Obligation ratio for the hour is calculated by dividing the Total Regulation Up Requirement for the hour by the ISO Hourly Total metered Demand. The Regulation Down to Load Obligation ratio for the hour is calculated by dividing the Total Regulation Down Requirement for the hour by ISO Hourly Total metered Demand. Exports are not considered metered demand.

5.6 SETTLEMENT AND REPORTING OF FLEXIBLE RAMPING COSTS

Since flexible ramping is procured based upon forecasted variability and uncertainties, when a resource deviates in a specific settlement interval, it cannot be concluded that the resource's actual deviation caused the flexible ramping product to be procured for that settlement interval. As a result, the ISO proposes to calculate the procurement impact from generation resources, imports and exports based upon the total cost and total deviations for the month.

Inter-SC trades currently support the daily transaction of energy, residual unit commitment (RUC) obligation, and AS obligation, between scheduling coordinators. The ISO proposes to expand the inter-SC trade functionality to allow the monthly transaction of the flexible ramping product obligation. This will allow supply resources and load with the opportunity to trade flexible ramping cost obligations in order to allow an individual supply resource to manage their deviations and impact on flexible ramping procurement targets.

5.7 FLEXIBLE RAMPING COST & DEVIATION 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 for cost buckets.

6. PLAN FOR STAKEHOLDER ENGAGEMENT

Item	Date
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

7. NEXT STEPS

The ISO will discuss the revised straw proposal with stakeholders at a meeting to be held on December 5, 2011. The ISO is seeking written comments on the revised straw proposal by December 12, 2011. Stakeholder comments should be sent to FRP@caiso.com.

APPENDIX A: NOMENCLATURE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

UU the set of upward variability or uncertainty sources

UD the set of downward variability or uncertainty sources

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

I_{FRU}^{DA} the set of upward flexible ramping awards in day-ahead market

I_{SPIN}^{DA} the set of non-contingent spinning awards in day-ahead market and non-contingent non-spinning awards in day-ahead market that become online in RTPD

$FRU_{i,t}^{DA}$ upward flexible ramping procured in day-ahead from resource *i* at time interval t

$SPIN_{i,t}^{DA}$ non-contingent spinning reserve procured in day-ahead market or non-contingent non-spinning reserve procured in day-ahead market that is online in RTPD from resource *i* at time interval $t\lambda_t^{FRU}$ shadow price of upward flexible ramping constraint at time interval t

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

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

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

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

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

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

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

The convention of the optimization model follows T. Wu and M. Rothleder et al. 2004.[7] 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,[8] which is a function of the generation output level, and the following model can be generalized to dynamic ramp rates without problem. As a convention, assume ramp rates are specified in MW/minute.

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

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

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

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

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

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

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

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

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

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[7] 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.

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

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

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

Upward ramping sharing[9] 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[1] This constraint limits the extent to which the awards of regulation-down and downward flexible ramping product can share the resource's ramping capability with the ramp used to support the changes in energy.

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

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.

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

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