Flexible Ramping Product

Draft Final Technical Appendix

January 25, 2016

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1. Introduction

This technical appendix documents the proposed design for a market-based flexible ramping product (FRP). The ISO is proposing the FRP to maintain power balance in the real-time dispatch and appropriately compensate ramping capability.

The ISO issued a ~~revised~~ draft final technical appendix on ~~November 16~~December 17, 2015. This addendum to the draft final technical appendix includes ~~clarifications and minor edits from the revised draft.~~ a proposed modification to the formulation for capacity constraints to ensure sufficient ramp is procured to support the projected change in dispatch without over-constraining the dispatch if it is reduced as a result of economic or limit changes. The following clarifications and changes to the FRP design from the ~~June 10~~December 17, 2015 draft have been included:

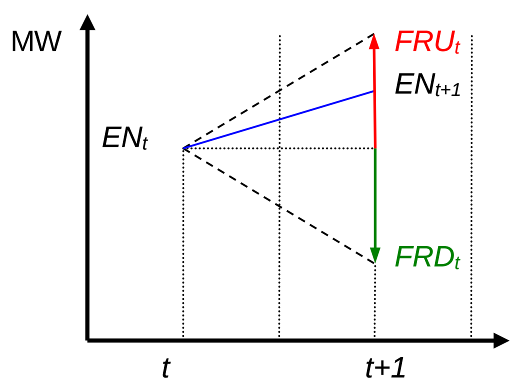
- Modified the capacity constraints (see section 5.2) to allow netting of FRU and FRD to allow for a more flexible dispatch.
- Corrected table 11 which shows the settlement of intertie schedule changes in both FMM and RTD due to hourly schedule changes.

2. Generalized flexible ramping capacity model

This section provides a brief overview of the flexible ramping capacity model in order to illustrate the flexible ramping procurement concept. For simplicity, the ISO does not include any ancillary services below; however, the full model will include ancillary service constraints.

Figure 1 shows the potential flexible ramping up and down awards for an online resource in time period *t* that can be procured based on the resource's ramping capability from t to t+1.

FIGURE 1: SIMPLIFIED FRP ILLUSTRATION OF CONCEPTUAL MODEL



The dashed lines represent the upward and downward ramping capability of the resource from its energy schedule in time period t. The flexible ramping up and down awards are limited by the ramping capability of the resource. The flexible ramping award may also include capacity that is needed to meet the scheduled ramping needs between t and t+1.

Both energy schedules (EN_t, EN_{t+1}) and flexible ramp awards (FRU_t, FRD_t) are calculated simultaneously by the market optimization engine. The only exception is the initial point (EN_0) of where the resource is scheduled in t-1, which is a fixed input for the ramp to the resource's energy schedule in time period t. These control variables are constrained by the following set of capacity and ramp constraints:

~~$\max(EN_t + FRU_t, EN_{t+1}) \leq UEL_{t+1}$~~	$\max(EN_t + FRU_t, EN_{t+1}) \leq UEL_{t+1}$
~~$\min(EN_t + FRD_t, EN_{t+1}) \geq LEL_{t+1}$~~	$\min(EN_t + FRD_t, EN_{t+1}) \geq LEL_{t+1}$
~~$RRD(EN_t, T) \leq FRD_t \leq 0$~~	$RRD(EN_t, T) \leq FRD_t \leq EN_{i,t+1} - EN_{i,t}$
~~$0 \leq FRU_t \leq RRU(EN_t, T)$~~	$EN_{i,t+1} - EN_{i,t} \leq FRU_t \leq RRU(EN_t, T)$
~~$RRD(EN_t, T) \leq EN_{t+1} - EN_t \leq RRU(EN_t, T)$~~	$RRD(EN_t, T) \leq EN_{t+1} - EN_t \leq RRU(EN_t, T)$

$EN_{i,t}$	Energy schedule of dispatchable Resource *i* in time period *t* (positive for supply and negative for demand).
$FRU_{i,t}$	Flexible Ramp Up award (algebraic) of Resource i in time period t.
$FRD_{i,t}$	Flexible Ramp Down award (~~non-positive~~algebraic) of Resource i in time period t.
$UEL_{i,t}$	Upper Economic Limit of Resource i in time period t.
$LEL_{i,t}$	Lower Economic Limit of Resource i in time period t.
$RRU_i(EN, T)$	Piecewise linear ramp up capability function of Resource *i* for time interval duration *T*.
$RRD_i(EN, T)$	Piecewise linear ramp down capability function (non-positive) of Resource *i* for time interval duration *T*.

The FRP will help the system to maintain and use dispatchable capacity. It will be procured to meet five minute to five minute net system demand changes plus uncertainty[1] and will be modeled as a ramping capability constraint. Both the five-minute RTD and fifteen-minute real time unit commitment (RTUC) will schedule FRP throughout their dispatch horizon. Awards will be compensated according to marginal FRP prices in the financially binding RTD interval (the first interval) and in the FMM, which is the financially binding RTUC interval (the second interval). Modeling FRP in RTUC enables the market to commit or de-commit resources as needed to obtain sufficient upward or downward ramping capability.

FRU is allowed to be negative when the resource must be dispatched lower in the next interval because of an upper operating limit derate; similarly, FRD is allowed to be positive when the resource must be dispatched higher in the next interval because of a lower operating limit uprate.

3. Flexible ramping product summary

FRP will be procured and dispatched in both the RTD and RTUC using similar methodologies.

[1] Only resources that are 5-minute dispatchable can be used to meet the uncertainty portion of FRP. For non-dispatchable resources, a resource constraint will limit FRP award to forecasted movement. For interties, FRP awards in FMM will not exceed the forecasted movement because the schedule changes are fixed in RTD.

FRP is designed with specific constraints and ramping requirements to ensure that there is sufficient ramping capability available in the financially binding interval to meet the forecasted net load for the next interval and cover upwards and downwards forecast error or uncertainty of the next interval.

In RTD, the FRU and FRD requirements are determined using the forecasted five minute net demand variation. The forecasted net demand variation is made up of (1) the forecasted net load movement between the binding and first advisory interval and (2) the expected error in the advisory intervals RTD net demand forecast within a 95% confidence interval. The uncertainty for both FRU and FRD will be procured using a demand curve. The upward demand curve will be capped at $247/MW, which is $3/MW less than the contingency reserve relaxation parameter. The downward demand curve will be capped at ($155/MW) with is $3/MW higher than regulation down relaxation parameter.

The probability distribution function for the five minute net demand forecast error is approximated by a histogram constructed from historical observations obtained from consecutive RTD runs over time periods that represents similar real-time conditions. While the historical observations for five minute net demand errors are the foundational data for forecasting the flexible ramping requirement, additional information may be used as the ISO continuously improves the forecast of ramping capability needed. The ISO will describe any additional factors that scale the historical observations in the business practice manual. The net load forecast error sample for a given five-minute interval is calculated as the difference between observed net demand for the binding RTD solution for that interval and forecasted net demand for the corresponding advisory interval of the previous RTD run.

Figure 2 illustrates the FRP requirement when net load is ramping upward in the RTD.

FIGURE 2 FLEXIBLE RAMPING PRODUCT RTD REQUIREMENT ILLUSTRATIVE SINGLE INTERVAL EXAMPLE

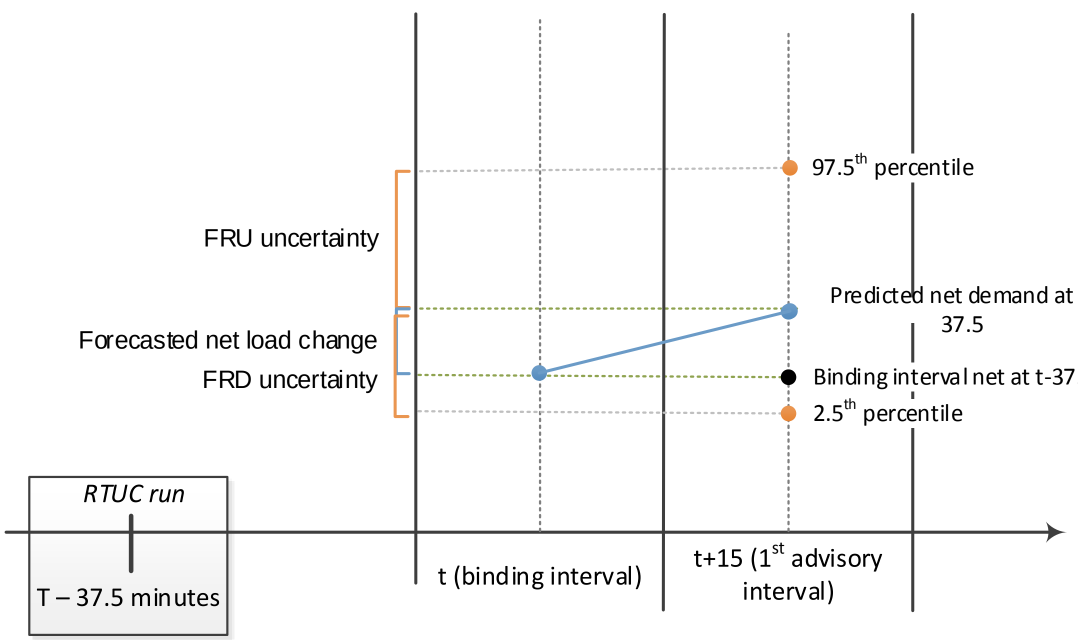


Figure 3 illustrates how the multi-interval optimization will treat FRP in each subsequent advisory interval in the real-time outlook.[2] Each advisory interval will reserve the forecasted net load change between successive advisory intervals and a portion of the predicted net load forecast error uncertainty, using an interval specific demand curve. If the outlook period is within the same hour and therefore the same histogram as the binding interval, the uncertainty portion of the demand curve will be the same in the binding and advisory FRP procurement. Outside of the hour, the uncertainty portion of the demand curve may change because the underlying histogram may be different (e.g. the histogram for 8:00 am may be different than the histogram for 9:00 am.) Therefore, there will be the same uncertainty in each subsequent advisory interval within hour 10:00, but in hour 11:00 the underlying demand curve may change.

The expected net load forecast change will be the difference between each subsequent advisory interval's and the previous adjacent interval's net load. The uncertainty for each advisory interval will be calculated using a net demand forecast within a 95% confidence interval.

FIGURE 3 FLEXIBLE RAMPING PRODUCT RTD REQUIREMENT ILLUSTRATIVE MULTI-INTERVAL EXAMPLE

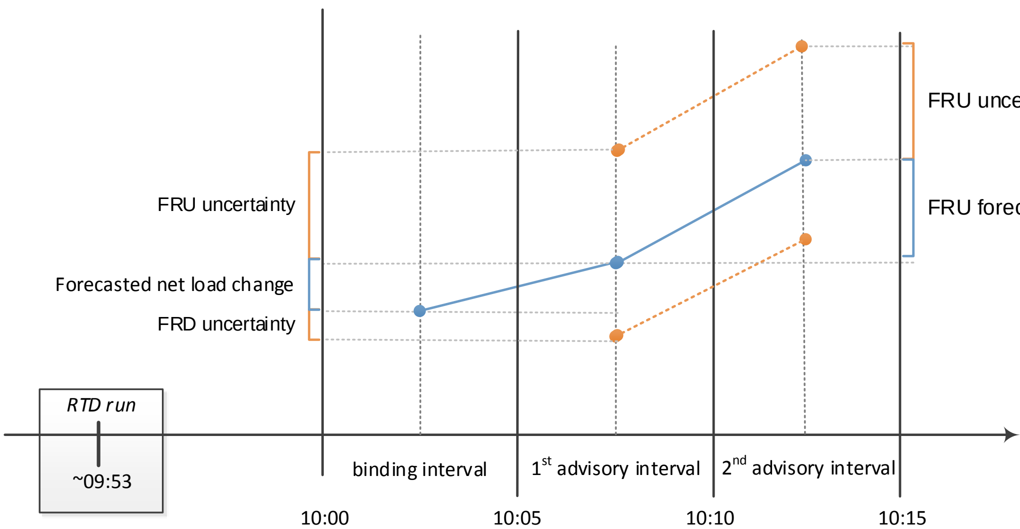


Figure 4 illustrates RTUC FRP procurement for the binding interval. Similar to RTD, in RTUC the FRU and FRD requirements are determined by the forecasted 15-minute net demand variation. The forecasted net demand variation is made up of (1) the forecasted net load change between the binding and first advisory interval and (2) the highest expected error between the RTUC first advisory interval and the associated RTD binding interval within a 95% confidence interval.

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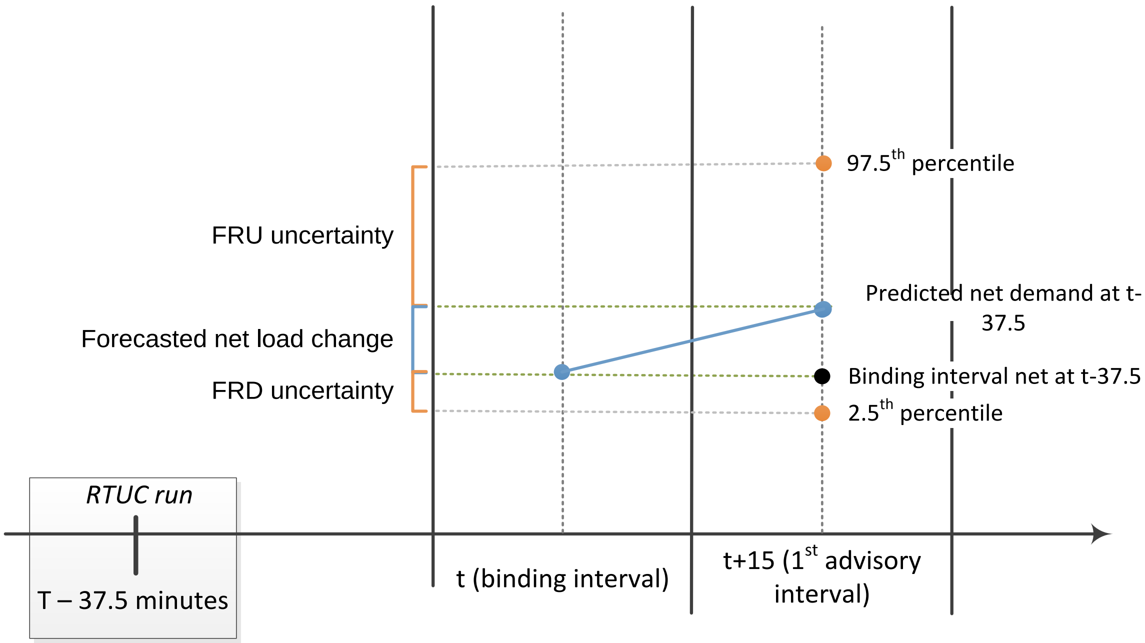
[2] RTD looks out between 9 and 13 intervals.

FIGURE 4 FLEXIBLE RAMPING PRODUCT RTUC REQUIREMENT ILLUSTRATIVE EXAMPLE



4. Flexible ramping requirement

4.1 Flexible ramping product total requirement

The FRP total requirement is calculated as the sum of the net demand forecast change across intervals and an additional amount for uncertainty within a 95% confidence interval. The uncertainty will be determined using historical net demand forecast errors and incorporated into a histogram. The histogram will be used to construct a demand curve that the market will use to procure FRP. The market will enforce FRP requirements in all binding and advisory intervals of the RTD and RTUC runs:

$$\left.\begin{aligned} FRUR_t &= FRUR_{\mathrm{ND}t} + FRUR_{\mathrm{U}t} \\ FRDR_t &= FRDR_{\mathrm{ND}t} + FRDR_{\mathrm{U}t} \end{aligned}\right\}, t = 1,2,\dots,N-1$$

t	Time period (interval) index.
N	The number of time periods in the time horizon.
$FRUR_t$	Total Flexible Ramp Up requirement in time period *t*.
$FRUR_{\mathrm{ND}t}$	Flexible Ramp Up requirement due to net demand forecast change in time period *t*.
$FRUR_{\mathrm{U}t}$	Flexible Ramp Up requirement due to uncertainty within specified confidence interval in time period *t*.
$FRDR_t$	Total Flexible Ramp Down requirement (non-positive) in time period *t*.

$FRDR_{\mathrm{ND}t}$	Flexible Ramp Down requirement (non-positive) due to net demand forecast change in time period *t*.
$FRDR_{\mathrm{U}t}$	Flexible Ramp Down requirement due to uncertainty within specified confidence interval in time period *t*.

4.2 Flexible ramping requirement for net demand forecast movement

The minimum FRP requirement is the forecasted real ramping need between intervals. For each binding interval, the market will use the requirement below to procure enough flexible ramping need to meet the forecasted net demand in the next advisory interval. Below is the mathematical representation of the minimum ramping requirement.

The flexible ramp requirement due to net demand forecast change exists only in the direction the net demand forecast is changing; it is zero in the opposite direction:

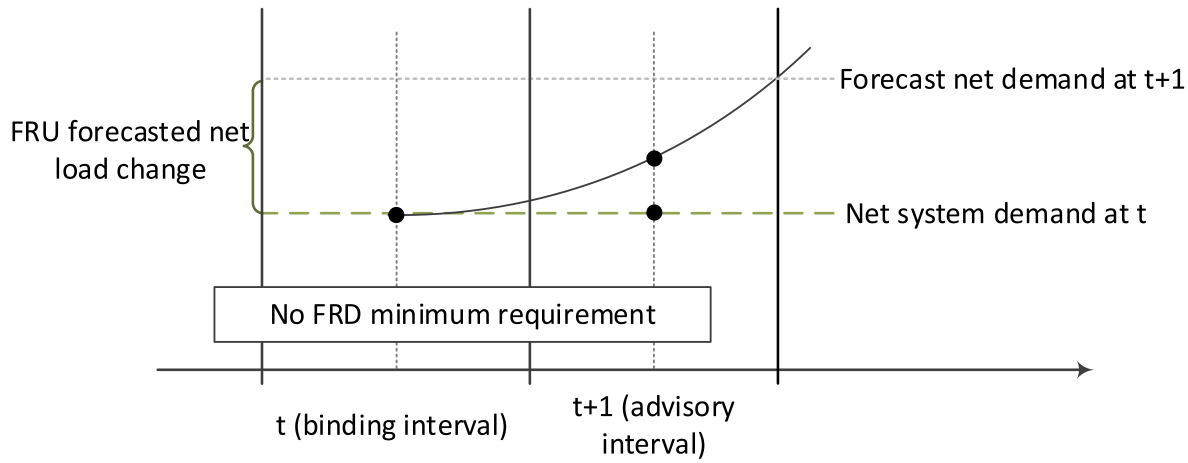
$$\left.\begin{aligned} FRUR_{\mathrm{ND}t} &= \max(0, \Delta ND_t) \\ FRDR_{\mathrm{ND}t} &= \min(0, \Delta ND_t) \end{aligned}\right\}, t = 1,2, \ldots, N-1$$

$$\textbf{Where}: \Delta \mathrm{ND_t} = ND_{t+1} - ND_t$$

ND_t	Net demand forecast in time period *t*.
$FRUR_{\mathrm{ND}t}$	Flexible Ramp Up requirement due to net demand forecast change in time period *t*.
$FRDR_{Ut}$	Flexible Ramp Down requirement due to uncertainty within specified confidence interval in time period t.

The ISO market will only set a FRU or FRD minimum requirement in the event that the forecasted net demand is moving in the same direction as the up or down requirement. Therefore, when the net demand is ramping upward there will not be a minimum FRD requirement, and vice versa. Figure 5 shows an illustrative example of a minimum FRU requirement. In this situation, there is no minimum FRD requirement.

FIGURE 5 FLEXIBLE RAMPING PRODUCT MINIMUM REQUIREMENT



4.3 Flexible ramping requirement due to uncertainty

The ISO market will procure additional flexible ramping capability using the demand curve based on net demand forecast uncertainty of the next interval. If the supply price is lower, FRP will be procured closer to the maximum ramping requirement. If the supply price is higher, FRP will be procured closer to the minimum requirement.

The flexible ramp requirement due to uncertainty is calculated as follows:

$$\left.\begin{aligned} FRUR_{Ut} &= \max(0, EU_t + FRDR_{\mathrm{ND}t}) \\ FRDR_{Ut} &= \min(0, ED_t + FRUR_{\mathrm{ND}t}) \end{aligned}\right\}, t = 1,2,\dots,N-1$$

Where:

$$\left.\begin{aligned} EU_t &= \max(0, PU_t) \\ \int_{-\infty}^{PU_t} p_t(\varepsilon)\, d\varepsilon &= CLU \end{aligned}\right\}, t = 1,2,\dots,N-1$$

$$\left.\begin{aligned} ED_t &= \min(0, PD_t) \\ \int_{-\infty}^{PD_t} p_t(\varepsilon)\, d\varepsilon &= CLD \end{aligned}\right\}, t = 1,2,\dots,N-1$$

$FRUR_{\mathrm{U}t}$ Flexible Ramp Up requirement due to uncertainty within specified confidence interval in time period *t*.

$FRDR_{\mathrm{U}t}$ Flexible Ramp Down requirement due to uncertainty within specified confidence interval in time period *t*.

$FRUR_{\mathrm{ND}t}$	Flexible Ramp Up requirement due to net demand forecast change in time period *t*.
$FRDR_{\mathrm{ND}t}$	Flexible Ramp Down requirement (non-positive) due to net demand forecast change in time period *t*.
EU_t	Flexible Ramp Up uncertainty at the upper confidence level in time period t.
ED_t	Flexible Ramp Down uncertainty (negative) at the lower confidence level in time period t.
$p_t(\varepsilon)$	Probability distribution function for the average five minute net demand forecast error in time period t, approximated by a histogram compiled from historical observations.
PU_t	Cumulative probability of net demand forecast error at or below the upper confidence level in time period *t*.
PD_t	Cumulative probability of net demand forecast error at or below the lower confidence level in time period *t*.
CLU	Flexible ramp uncertainty upper confidence level, e.g., 97.5%.
CLD	Flexible ramp uncertainty lower confidence level, e.g., 2.5%.

The above formula is illustrated in Figure 6 and Figure 7.

FIGURE 6 FLEXIBLE RAMPING PRODUCT REQUIREMENT DUE TO UNCERTAINTY

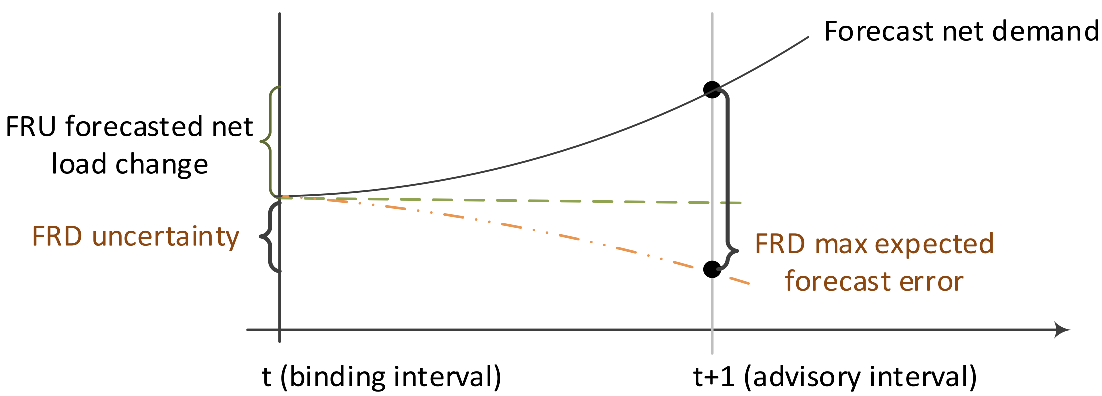
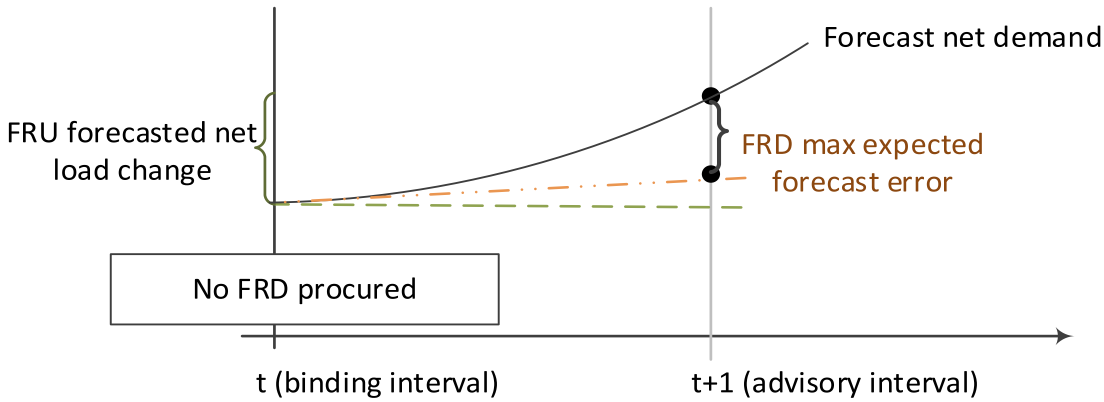


Figure 6 illustrates an interval where the maximum expected downward forecast error (max {ED_t}) is greater than the FRU minimum requirement. The ISO will then procure the portion between the maximum expected forecast error and net load forecast at time t using a demand curve. This is illustrated as the difference between the dashed green line and the dashed orange line.

Figure 7, below, illustrates an interval where the maximum expected downward forecast error (max {ED_t}) is less than the FRU minimum requirement. In this situation the ISO will not need additional FRD capacity.

FIGURE 7: FLEXIBLE RAMPING PRODUCT WITH NO FLEXIBLE RAMPING DOWN MINIMUM OR DEMAND REQUIREMENT

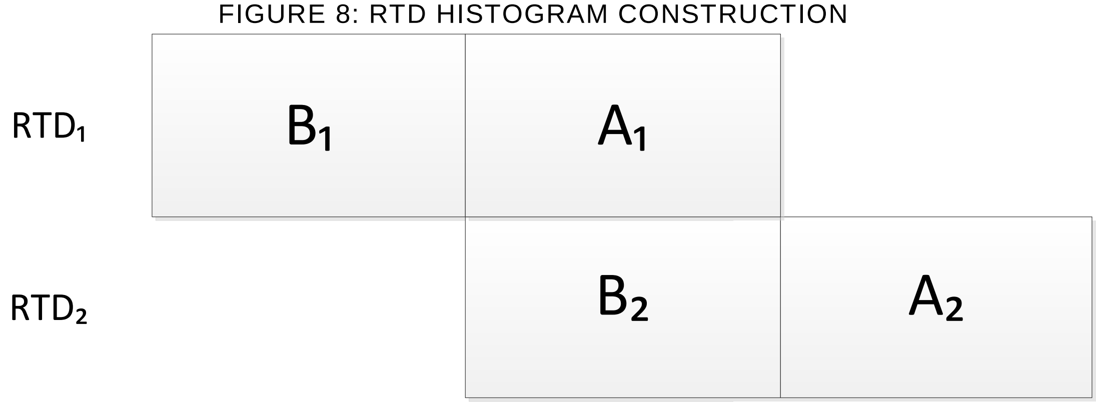


4.3.1 Using historical data to forecast uncertainty

The ISO will construct histograms as an approximation of the probability distribution of net demand forecast errors to be used to procure for uncertainty. It will construct separate histograms for FRU and FRD for each hour, separately for RTD and RTUC.

The histogram for RTD will be constructed by comparing the net demand for the first advisory RTD interval to the net load in the same time interval for the next financially binding RTD run. For example, Figure 8 shows two consecutive RTD 5-minute market runs, RTD_1 and RTD_2. The ISO will construct the histograms by subtracting the net demand from the first market run used for the first advisory interval (A1) from the net demand the second market run used for the binding interval (B_2).

FIGURE 8: RTD HISTOGRAM CONSTRUCTION



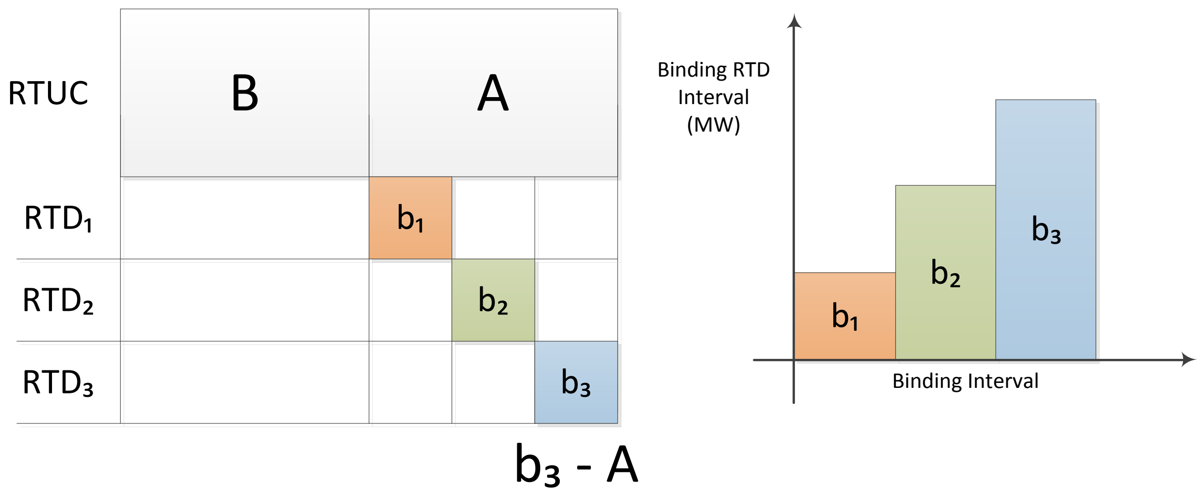
$$B_2 - A_1$$

For RTUC, the ISO will construct separate histograms for FRU and FRD as follows:

- For FRU, the histograms will be constructed based on the difference of the net demand the market used in the FMM for the first advisory RTUC interval and the maximum net demand the market used for the three corresponding RTD intervals.
- For FRD, the histograms will be constructed based on the difference of the net demand the market used in the FMM for the first advisory RTUC interval and the minimum net demand the market used for the three corresponding RTD intervals.

Figure 9 shows two RTUC intervals: the FMM (i.e. the RTUC binding interval) and the first advisory interval (labeled "A"). It illustrates how the FRU histogram will be constructed by comparing the net demand the FMM used for first advisory RTUC interval to the maximum net demand the market used for the corresponding three RTD binding intervals (b_1,b_2,b_3).

FIGURE 9: HISTOGRAM CONSTRUCTION IN RTUC



The FRU histogram will use the observation b_3 – A. This represents the maximum ramping need. The variable b_3, represents the maximum net load in the three RTD intervals. The FRD histogram will use observation b_1 – A as this is the minimum ramping need. Ultimately in this example, the FRD observation is positive and therefore will not be used directly in the demand curve creation. It will however be used to calculate the 95th percentile load forecast error and therefore needs to be captured in the histogram.

The ISO proposes to use a rolling 30 days, with a separate histogram for weekends and holidays, to evaluate the historical advisory RTUC imbalance energy requirement error pattern for each RTUC hour. The ISO will also evaluate if hours with similar ramping patterns could be combined to increase the sample size used in the historical analysis.

4.4 Market interval and Averaging Factor

To present the same mathematical formulation for both RTUC and RTD for simplicity, in the following sections we ignore the buffer interval in RTUC assuming there are *N*–1 FRU/FRD awards in both RTUC and RTD. Furthermore, to make the formulation agnostic to the particular market application, the market interval is defined as follows:

$$T = \begin{cases} T_5 & \text{in RTD} \\ T_{15} & \text{in RTUC} \end{cases}$$

For the same reason, since the FRU/FRD awards in RTUC are three 5min back-to-back awards covering the 15min ramp from one 15min interval to the next, it is convenient to define an averaging factor as follows:

$$AF = \begin{cases} 1 & \text{in RTD} \\ \dfrac{T_{15}}{T_5} & \text{in RTUC} \end{cases}$$

T	Application time interval.
T_5	RTD time interval (5min).
T_{15}	RTUC time interval (15min).
AF	Averaging factor.

Consequently, multiplying the FRU/FRD awards with the averaging factor makes the mathematical formulation applicable to both RTUC and RTD.

~~4.4~~4.5 Flexible ramping product requirement constraints

The requirement constraints for the procurement of FRU/FRD are as follows:

$$\left.\begin{aligned} \sum_i FRU_{i,t} + FRUS_t = FRUR_t \\ \sum_i FRD_{i,t} + FRDS_t = FRDR_t \end{aligned}\right\}, t = 1,2,\ldots,N-1$$

$$\left.\begin{aligned} AF \sum_i FRU_{i,t} + FRUS_t \geq FRUR_t \\ AF \sum_i FRD_{i,t} + FRDS_t \leq FRDR_t \end{aligned}\right\}, t = 1,2,\ldots,N-1$$

i	Resource index.
AF	Averaging factor.
$FRU_{i,t}$	Flexible Ramp Up award (algebraic) of Resource i in time period t.
$FRD_{i,t}$	Flexible Ramp Down award (~~non-positive~~algebraic) of Resource i in time period t.
$FRUS_t$	Flexible Ramp Up surplus in time period t.
$FRDS_t$	Flexible Ramp Down surplus (non-positive) in time period t.
$FRUR_t$	Total Flexible Ramp Up requirement in time period t.
$FRDR_t$	Total Flexible Ramp Down requirement (non-positive) in time period t.

Where the FRU/FRD surplus variables provide flexible ramp demand response for the entire flexible ramp requirement at an appropriate cost:

$$\left.\begin{array}{l}0 \le FRUS_t \le FRUR_t \\ 0 \ge FRDS_t \ge FRDR_t\end{array}\right\}, t = 1,2,\dots,N-1$$

~~4.5~~4.6 Flexible ramping product objective function

This section describes the objective and cost function of the FRP. The FRP will be procured to meet the predicted net demand variation and uncertainty requirements using a demand curve at the cost of expected power balance violations in absence of FRP.

$$C = \cdots + \sum_{t=1}^{N} \int_{0}^{FRUS_t} C\dot{S}U_t(FRUS_t)\, de + \sum_{t=1}^{N} \int_{0}^{FRDS_t} C\dot{S}D_t(FRDS_t)\, de$$

A surplus variable is used to determine the expected cost of not procuring a portion of the uncertainty. The FRU/FRD surplus cost function for the flexible ramp requirement due to uncertainty is the expected uncertainty multiplied by the relevant energy price cap:

$$\left.\begin{array}{l} CSU_t(FRUS_t) = PC \displaystyle\int_{EU_t - FRUS_t}^{EU_t} \big(e - (EU_t - FRUS_t)\big) * p_t(e)\, de, 0 \le FRUS_t \le FRUR_{Ut} \\ CSD_t(FRDS_t) = -PF \displaystyle\int_{ED_t - FRDS_t}^{ED_t} \big(e - (ED_t - FRDS_t)\big) * p_t(e)\, de, 0 \ge FRDS_t \ge FRDR_{Ut} \end{array}\right\},$$

$$t = 1,2,\dots,N-1$$

~~And~~The FRU/FRD demand curve is the incremental FRU/FRD surplus cost function, capped by the applicable FRU/FRD insufficiency administrative price:

$$\left.\begin{array}{l} \left.\begin{array}{l} CDU_t(FRUS_t) = \min\big(FRUP, C\dot{S}U_t(FRUS_t)\big) = \\ \min\left(FRUP, PC \displaystyle\int_{EU_t - FRUS_t}^{EU_t} p_t(e)\, de\right) \end{array}\right\}, \quad 0 \le FRUS_t \le FRUR_{Ut} \\ \left.\begin{array}{l} CDD_t(FRDS_t) = \min\big(FRDP, C\dot{S}D_t(FRDS_t)\big) = \\ \max\left(FRDP, PF \displaystyle\int_{ED_t - FRDS_t}^{ED_t} p_t(e)\, de\right) \end{array}\right\}, \quad 0 \ge FRDS_t \ge FRDR_{Ut} \end{array}\right\}, t$$

$$= 1,2,\dots,N-1$$

The FRU/FRD demand curve is extended to the total flexible ramp requirement at the applicable FRU/FRD insufficiency administrative price:

~~$$\left.\begin{matrix} \dot{CSU}_t(FRUS_t) = \dot{CSU}_t(FRUR_{Ut}), FRUR_{Ut} < FRUS_t \le FRUR_t \\ \dot{CSD}_t(FRDS_t) = \dot{CSD}_t(FRDR_{Ut}), FRDR_{Ut} > FRUS_t \ge FRDR_t \end{matrix}\right\}, t = 1,2,\dots,N-1$$~~

$$\left.\begin{matrix} CDU_t(FRUS_t) = FRUP, FRUR_{Ut} < FRUS_t \le FRUR_t \\ CDD_t(FRDS_t) = FRDP, FRDR_{Ut} > FRUS_t \ge FRDR_t \end{matrix}\right\}, t = 1,2,\dots,N-1$$

e	Average 5min net demand forecast error
$p_t(e)$	Probability distribution function for the average 5min net demand forecast error in time period *t*, approximated by a histogram compiled from historical observations.
$\cdot$	Denotes derivative.
$FRUS_t$	Flexible Ramp Up surplus in time period *t*.
$FRDS_t$	Flexible Ramp Down surplus (non-positive) in time period *t*.
$CSU_t(FRUS_t)$	Flexible Ramp Up surplus cost function in time period *t*.
$CSD_t(FRDS_t)$	Flexible Ramp Down surplus cost function in time period *t*.
$FRUR_{Ut}$	Flexible Ramp Up requirement due to uncertainty within specified confidence interval in time period *t*.
$FRDR_{Ut}$	Flexible Ramp Down requirement due to uncertainty within specified confidence interval in time period *t*.
C	Objective function.
PC	Bid Price ceiling, currently $1,000/MWh.
PF	Bid Price floor, currently –$155/MWh.
EU_t	Flexible Ramp Up uncertainty at the upper confidence level in time period t.
ED_t	Flexible Ramp Down uncertainty (negative) at the lower confidence level in time period t.
$CDU_t(FRUS_t)$	Flexible Ramp Up demand curve in time period t.
$CDD_t(FRDS_t)$	Flexible Ramp Down demand curve in time period t.
$FRUP$	Flexible Ramp Up insufficiency administrative price.
$FRDP$	Flexible Ramp Down insufficiency administrative price (negative).
$FRUR_t$	Total Flexible Ramp Up requirement in time period t.
$FRDR_t$	Total Flexible Ramp Down requirement (non-positive) in time period t.

The cost functions and their derivatives above can be approximated using the relevant histogram compiled from historical observations, leading to a stepwise incremental cost function that must be forced to be monotonically increasing for *FRUS* and monotonically decreasing for *FRDS*, as required by market optimization solvers for convergence.

~~4.5.1~~4.6.1 Demand curve will be used to procure FRP to meet uncertainty

The power balance penalty cost function:

Power Balance MW violation	Penalty ($/MWh)
-300 to 0	$-155
0 to 400	$1000

The net load forecast error probability distribution function:

Net Load Forecast Error MW bin	Probability
-300 to -200	1%
-200 to -100	2%
-100 to 0	44.8%
0 to 100	50%
100 - 200	1.4%
200 - 300	0.5%
300 - 400	0.3%

For optimization efficiency, it is better to construct the demand curve as a demand response (requirement reduction) assigned to a surplus variable as shown in the objective function formula above. This is the mirror image of the demand curve across the vertical axis and can be constructed integrating the histogram from the maximum surplus towards the center.

The cost function for the FRU/FRD surplus is derived from the histogram as follows:

FRP (MW)		Surplus (MW)		Probability	Penalty ($/MWh)	Demand Curve Price ($/MWh)
-200	-300	0	-100	0.01	–155	(.01/2) (-155) = –$.79
-100	–200	-100	-200	0.02	–155	(.02/2 + .01) (-155) = -$3.10
0	–100	-200	-300	0.448	–155	(.448/2 + .02 + .01) (–155) = –$39.37
0	100	300	400	0.5	1,000	(.5/2 + .014 +.005 +.003) 1000 = $272.00
100	200	200	300	0.014	1,000	(.014/2 +.005 +.003) 1000 = $15.00
200	300	100	200	0.005	1,000	(.005/2 + .003) 1000 = $5.50
300	400	0	100	0.003	1,000	(.003/2) 1000 = $1.50
Start	End	Start	End	Probability	Penalty ($/MWh)	Demand Curve Price ($/MWh)

The step size that is used to discretize the net load forecast error distribution function and the corresponding flexible ramping product demand curve may change size depending on the distribution of errors. In the event the demand curve is non-monotonic, the ISO will set each non-monotonic price segment at the last monotonic segment price.

5. Flexible ramping resource constraints

5.1 Resource ramping capability constraints

FRP will be procured based on a constraint by its ramping capability within an interval:

$$\left.\begin{array}{l} 0 \le FRU_{i,t} \le RRU_i(EN_t, T_5) \\ RRD_i(EN_t, T_5) \le FRD_{i,t} \le 0 \end{array}\right\} \forall i, t = 1,2, \dots, N-1$$

~~For implementation, it is advantageous to use the same time domain for the *RRU*() and *RRD*() dynamic ramp functions, and since the energy schedules are constrained by cross-interval ramps, the FRU/FRD ramp constraints can be expressed on the same time domain for all market applications as follows:~~

$$\left.\begin{array}{l} 0 \le AF\ FRU_{i,t} \le RRU_i(EN_t, T) \\ RRD_i(EN_t, T) \le AF\ FRD_{i,t} \le 0 \end{array}\right\} \forall i, t = 1,2, \dots, N-1$$

~~Where *T* is the relevant market interval duration:~~

$$T = \begin{cases} T_5 & \text{in RTD} \\ T_{15} & \text{in RTUC} \end{cases}$$

~~And the averaging factor is defined as follows:~~

$$AF = \begin{cases} 1 & \text{in RTD} \\ \frac{T_{15}}{T_5} & \text{in RTUC} \end{cases}$$

$$\left.\begin{array}{l} EN_{i,t+1} - EN_{i,t} \le AF\ FRU_{i,t} \le RRU_i(EN_t, T) \\ RRD_i(EN_t, T) \le AF\ FRD_{i,t} \le EN_{i,t+1} - EN_{i,t} \end{array}\right\} \forall i, t = 1,2,\dots,N-1$$

~~T~~	~~Time interval.~~
~~T_5~~ T	~~RTD~~Application time interval ~~(5min).~~.
~~T_{15}~~	~~RTUC time interval (15min).~~
AF	Averaging factor.
$FRU_{i,t}$	Flexible Ramp Up award (algebraic) of Resource *i* in time period *t*.
$FRD_{i,t}$	Flexible Ramp Down award (~~non-positive~~algebraic) of Resource *i* in time period *t*.
$RRU_i(EN, T)$	Piecewise linear ramp up capability function of Resource i for time interval T.
$RRD_i(EN, T)$	Piecewise linear ramp down capability function (non-positive) of Resource i for time interval T.

5.2 Resource capacity constraints

A resource must have an energy bid to be eligible for FRP. Also, the resource's schedule must not be in a forbidden operating region or in a state of transition if it is a multi-stage generator.

The relevant capacity constraints for an online resource on regulation are as follows:

$$\left.\begin{array}{l} \max\left(LOL_{i,t+1}, LRL_{i,t+1}\right) \le EN_{i,t} + AF\ FRD_{i,t} + RD_{i,t+1} \\ EN_{i,t} + AF\ FRU_{i,t} + NR_{i,t+1} + SR_{i,t+1} + RU_{i,t+1} \le \min\left(UOL_{i,t+1}, URL_{i,t+1}, CL_{i,t+1}\right) \\ LEL_{i,t+1} - AF\ FRD_{i,t} \le EN_{i,t} \le UEL_{i,t+1} - AF\ FRU_{i,t} \end{array}\right\} \forall i, t = 1,2,\dots,N-1$$

The relevant capacity constraints for an online resource not on regulation are as follows:

~~$$\left.\begin{array}{l} LOL_{i,t+1} \le EN_{i,t} + AF\left(FRU_{i,t} + FRD_{i,t}\right) \\ EN_{i,t} + AF\left(FRU_{i,t} + FRD_{i,t}\right) + NR_{i,t+1} + SR_{i,t+1} \le \min\left(UOL_{i,t+1}, CL_{i,t+1}\right) \\ LEL_{i,t+1} - AF\left(FRU_{i,t} + FRD_{i,t}\right) \le EN_{i,t} \le UEL_{i,t+1} - AF\left(FRU_{i,t} + FRD_{i,t}\right) \end{array}\right\} \forall i, t = 1,2,\dots,N - 1$$~~

$$\left.\begin{array}{l} LOL_{i,t+1} \le EN_{i,t} + AF\ FRD_{i,t} \\ EN_{i,t} + AF\ FRU_{i,t} + NR_{i,t+1} + SR_{i,t+1} \le \min\left(UOL_{i,t+1}, CL_{i,t+1}\right) \\ LEL_{i,t+1} - AF\ FRD_{i,t} \le EN_{i,t} \le UEL_{i,t+1} - AF\ FRU_{i,t} \end{array}\right\} \forall i, t = 1,2,\dots,N-1$$

AF	Averaging factor.
$UOL_{i,t}$	Upper Operating Limit of Resource *i* in time period *t*.
$LOL_{i,t}$	Lower Operating Limit of Resource *i* in time period *t*.
$URL_{i,t}$	Upper Regulating Limit of Resource *i* in time period *t*.
$LRL_{i,t}$	Lower Regulating Limit of Resource *i* in time period *t*.
$UEL_{i,t}$	Upper Economic Limit of Resource *i* in time period *t*.
$LEL_{i,t}$	Lower Economic Limit of Resource *i* in time period *t*.
$CL_{i,t}$	Capacity Limit for Resource *i* in time period *t*; $LOL_{i,t} \leq CL_{i,t} \leq UOL_{i,t}$; it defaults to $UOL_{i,t}$.
$EN_{i,t}$	Energy schedule of Resource *i* in time period *t* (positive for supply and negative for demand).
$RU_{i,t}$	Regulation Up award of Resource *i* in time period *t*.
$RD_{i,t}$	Regulation Down award (non-positive) of Resource *i* in time period *t*.
$SR_{i,t}$	Spinning Reserve award of Resource *i* in time period *t*.
$NR_{i,t}$	Non-Spinning Reserve award of Resource *i* in time period *t*.
$FRU_{i,t}$	Flexible Ramp Up award (algebraic) of Resource *i* in time period *t*.
$FRD_{i,t}$	Flexible Ramp Down award (~~non-positive~~algebraic) of Resource *i* in time period *t*.

6. Properties of flexible ramping

This section presents simple examples of FRP to demonstrate the properties and benefits of flexible ramping under the assumption that net load is accurately predicted.

These examples will show:

- The market's multi-interval look-ahead optimization, which currently produces a "composite" energy price, which consists of a pure energy price and a ramping price. The composite energy price may not be consistent with the resource's energy offer price if only the binding interval is settled, and may trigger bid cost recovery. The composite energy price is also very sensitive to deviations from the expected net system demand level because there is no dispatch margin built in the optimization. The composite energy price can be very volatile.

- FRP can decompose the pure energy price and flexible ramping prices, and provide more transparent and less volatile price signals. These prices are also more consistent with the energy offers, and reduce the need for bid cost recovery. These are advantages of FRP even if net system demand could be predicted with high accuracy.

For simplicity, the examples will only consider the interaction between energy and the flexible ramping product, and ignore ancillary services.

6.1 Upward flexible ramping

Assume there are two 500 MW online resources in the system that could provide FRU. The bids and parameters of the two generators are listed in Table 1. G1 has 100 MW/minute ramp rate, and G2 has 10 MW/minute ramp rate. G1 is more economic in energy than G2. They both have zero cost bids for providing flexible ramping.

TABLE 1: RESOURCE BIDS, INITIAL CONDITION AND OPERATIONAL PARAMETERS

Generation	Energy Bid	Initial Energy	Ramp Rate	Pmin	Pmax
G1	$25	400 MW	100 MW	0	500 MW
G2	$30	0	10 MW	0	500 MW

Scenario 1: Single interval RTD optimization without upward flexible ramping with load at 420 MW.

In scenario 1, load is met by the most economic resource G1, and G1 sets the LMP at $25.

TABLE 2: SINGLE-INTERVAL RTD DISPATCH WITHOUT UPWARD FLEXIBLE RAMPING

	Interval t (LMP=$25)	
Generation	**Energy**	**Flex-ramp up**
G1	420 MW	-
G2	0 MW	-

Scenario 2: Single interval RTD optimization with upward flexible ramping with load at 420 MW and an upward flexible ramping requirement at 170 MW.

The solution for scenario 2 is listed in Table 3. In scenario 2, in order to meet 170 MW upward flexible ramping, G1 is not dispatched for as much energy to make room for upward flexible ramping. As a result, G1 does not have extra capacity to meet extra load, and LMP is set by G2 at $30. The upward flexible ramping requirement caused the LMP to increase compared with scenario 1. FRU price is set by G1's energy opportunity cost $30 – $25= $5.

TABLE 3: SINGLE-INTERVAL RTD DISPATCH WITH UPWARD FLEXIBLE RAMPING

	Interval t (LMP=$30, FRUP=$5)

Generation	Energy	Flex-ramp up
G1	380 MW	120 MW
G2	40 MW	50 MW

Scenario 3: Two-interval RTD optimization without upward flexible ramping with load (t) at 420 MW and load (t+5) at 590 MW.

The solution for scenario 3 is listed in Table 4. In scenario 3, there is no flexible ramping requirement. However, the look-ahead optimization projects a 170 MW of upward load ramp from interval t to t+5, which equals the upward flexible ramping requirement in scenario 2. The look-ahead optimization produces the same dispatch for interval t as in scenario 2, but different LMPs. The LMPs are different because there is an interaction between the energy price and flexible ramping price. Without the flexible ramping product, the look-ahead optimization still holds G1 back in interval t to meet the load in interval t+5, but G1 is still the marginal unit in interval t and sets the LMP at $25. G2 is the marginal unit for interval t+5 and sets the non-binding LMP for interval t+5 at $35 ($30 bid cost in interval t+5 plus $5 not bid cost not recovered in interval t).

TABLE 4: LOOK-AHEAD RTD DISPATCH WITHOUT UPWARD FLEXIBLE RAMPING

	Interval t (LMP=$25)	**Interval t+5 (LMP=$35)**
Generation	**Energy**	**Energy**
G1	380 MW	500 MW
G2	40 MW	90 MW

Scenario 4: Two-interval RTD optimization with upward flexible ramping with load (t) at 420 MW and load (t+5) at 590 MW. The upward flexible ramping requirement at (t) is 170.01 MW.

In scenario 4, both flexible ramping and look-ahead are modeled in the optimization. In order to have uniquely determined prices, we set upward flexible ramping requirement slightly higher than expected load ramp 170 MW. The results are listed in Table 5 which converge to scenario 2 in the first interval. If the flexible ramping requirement is slightly lower than the expected load ramp, the solution would converge to scenario 3.

TABLE 5: LOOK-AHEAD RTD DISPATCH WITH FRU REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED UPWARD LOAD RAMP

	Interval t (LMP=$30, FRUP=$5)		**Interval t+5 (LMP=$30)**	
Generation	**Energy**	**Flex-ramp up**	**Energy**	**Flex-ramp up**
G1	379.99 MW	120.01 MW	500 MW	-

G2	40.01 MW	50 MW	90 MW	-

TABLE 6: POSSIBLE LOOK-AHEAD RTD DISPATCH WITHOUT FLEXIBLE RAMPING IN INTERVAL T+5

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

6.2 Downward flexible ramping

Assume two 500 MW resources are online in the system that can provide flexible ramping. The bids and parameters of the two generators are listed in Table 7. G1 has 10 MW/minute ramp rate, and G2 has 100 MW/minute ramp rate. G1 is more economic in energy than G2. They both have zero cost for providing flexible ramping.

TABLE 7: RESOURCE BIDS, INITIAL CONDITION AND OPERATIONAL PARAMETERS

Generation	Energy Bid	Flex Ramp Up	Flex Ramp Down	Energy Initial	Ramp rate	Pmin	Pmax
G1	$25	0	0	300 MW	10 MW/min	0	500 MW
G2	$30	0	0	100 MW	100 MW/min	0	500 MW

Scenario 1: Single interval RTD optimization without downward flexible ramping with load at t = 380 MW

The solution for scenario 1 is listed in Table 8. In scenario 1, load is met by both G1 and G2, and G2 sets the LMP at $30. Although G1 is more economic than G2, its output 350 MW has been limited by its ramp rate 10 MW/minute from its initial condition 300 MW, so it cannot set the LMP.

TABLE 8: SINGLE-INTERVAL RTD DISPATCH WITHOUT DOWNWARD FLEXIBLE RAMPING

	Interval t (LMP=$30)	
Generation	**Energy**	**Flex-ramp down**
G1	350 MW	-
G2	30 MW	-

Scenario 2: Single interval RTD optimization with downward flexible ramping with load at t =

380 MW and downward flexible ramping requirement at t = 170 MW

The solution for scenario 2 is listed in Table 9. In scenario 2, in order to meet 170 MW downward flexible ramping, G2 needs to be dispatched up in order to provide downward flexible ramping. As a result, G1's output will be reduced in order to maintain the power balance, and G1 sets the LMP at $25. Note the downward flexible ramping requirement causes the LMP to decrease compared with scenario 1. The downward flexible ramping price FRDP is set by G2's energy price deficit $30 – $25= $5. The FRDP price is to compensate G2 such that G2's revenue including both energy and FRD can cover its energy bid cost $30. As a result, there is no revenue shortage for G2, and no need for bid cost recovery.

TABLE 9: SINGLE-INTERVAL RTD DISPATCH WITH DOWNWARD FLEXIBLE RAMPING

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

Scenario 3: Two-interval RTD optimization without downward flexible ramping with load at t = 380 MW and load at t+5 = 210 MW.

The solution for scenario 3 is listed in Table 10. In scenario 3, there is no FRD requirement. However, the look-ahead optimization projects a 170 MW of downward load ramp from interval t to t+5, which equals the downward flexible ramping requirement in scenario 2. The look-ahead optimization produces the same dispatch for interval t as in scenario 2, but different LMPs. The dispatch is the same because the look-ahead load ramp also requires the same amount of ramping capability as the flexible ramping requirement in interval t. The LMPs are different because there is an interaction between the energy price and flexible ramping price. When net system demand is decreasing, which creates more downward ramp need, the look-ahead optimization will increase the energy price in the binding interval (for similar but opposite reasons as described in the FRU example in scenario 3 in the preceding section 6.1).

TABLE 10: LOOK-AHEAD RTD DISPATCH WITHOUT DOWNWARD FLEXIBLE RAMPING

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

Scenario 4: Two-interval RTD optimization with downward flexible ramping with load t = 380 MW and load at t+5 = 210 MW. The downward flexible ramping requirement at (t) is 170.01.

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

TABLE 11: LOOK-AHEAD RTD DISPATCH WITH FRD REQUIREMENT SLIGHTLY HIGHER THAN EXPECTED DOWNWARD LOAD RAMP

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

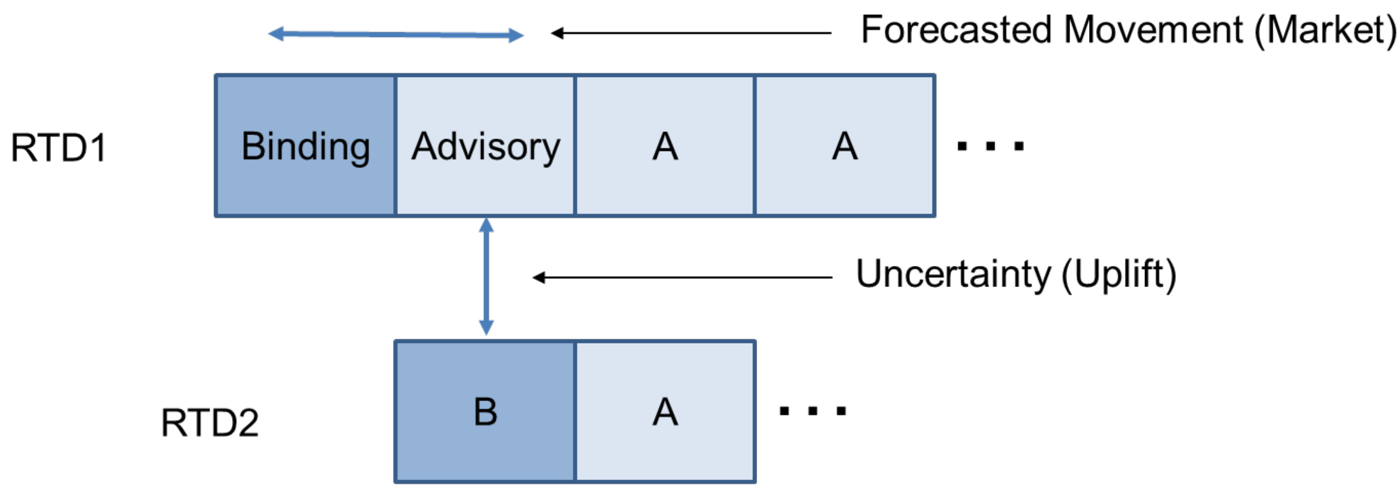
7. Settlement

The ISO will financially settle FRP in the fifteen-minute market and the five-minute market. The financial settlement of FRP is separated into two settlement calculations:

- A direct settlement in the market for all forecasted movement.
- A settlement for FRP procured for uncertainty, based on observed load and non-dispatchable resource forecast error, allocated at the end of the month through an uplift.

Figure 10 below shows two RTD runs and illustrates the difference between the FRP procured for forecasted movement settled directly in the market and the FRP procured for uncertainty allocated at the end of the month through an uplift. The forecasted movement will be settled in every FMM or RTD settlement interval and will be the difference between the “horizontal” binding and advisory intervals. Uncertainty will be settled monthly through the difference of the “vertical” binding and advisory intervals.

FIGURE 10 BINDING AND ADVISORY INTERVAL REPRESENTATION



The market will enforce a single requirement for each direction of the flexible ramping product (i.e. FRU, FRD) which covers both forecasted movement and uncertainty. This results in a single price for ramping capability to cover both forecasted movement and uncertainty.

The FRP settlement for forecasted movement will be paid and charge in each settlement interval with the same settlement timing as energy imbalances. The FRP settlement for uncertainty will be paid and charged at the end of the month to eliminate the need for a monthly resettlement.

7.1 Direct settlement for forecasted movement

Forecasted movement will be settled in FMM at the FMM price. Any difference between FRP procured for the FMM forecasted movement and the RTD forecasted movement will be settled at the RTD FRP price. Note that the granularity difference between FMM and RTD can cause differences between the FMM awards and RTD awards. The same issue exists with energy settlements today.

For dispatchable and non-dispatchable supply, the settlement is calculated by resource for each 15-minute FMM and 5-minute RTD settlement interval. The ISO uses its forecast[3] for variable energy resources' output to clear the market but provides the option for variable energy resources to use their own forecast to schedule energy. The ISO will only use the ISO's forecast to calculate ramping awards for variable energy resources. This is to mitigate against variable energy resources adjusting the forecast of the advisory interval to receive payment for ramp. VERs could do this without financial cost because the advisory energy schedules are not

[3] In the energy imbalance market, the EIM entity must provide an independent third party forecast. This forecast is then used in the market. If the EIM entity does not have an independent third party forecast, the ISO will use its forecast provider.

financially binding.

For interties, the settlement is calculated for each schedule for each 15-minute and 5-minute settlement interval based upon the prescribed ramps. Hourly schedule changes have a 20 minute ramp. 15-minute schedule changes have a 10 minute ramp. The granularity differences between FMM and RTD will result in ramp settlement even if though a static intertie schedule cannot be changed in RTD. In addition, operational adjustments should be reflected prior to the start of the RTD optimization covering the relevant FMM interval; therefore, this change can be reflected in the forecasted movement of RTD is not a cause of uncertainty.

Table 11 illustrates the upward FRP settlement in both FMM and RTD for an hourly intertie schedule that is ramping from 100 MW in HE 02 to 150 MW in HE 03. The schedule change will result in settlements at both the FMM and RTD FRU price. This accurately reflects the upward ramping value the hourly intertie change provides, as the real-time market schedules and dispatches resources to meet current system conditions.

TABLE 11 INTERTIE MOVEMENT SETTLEMENT IN RTD AND FMM

	HE 02						HE 03					
	RTD7	RTD8	RTD9	RTD10	RTD11	RTD12	RTD1	RTD2	RTD3	RTD4	RTD5	RTD6
Prescribed hourly ramp (Avg. MW)	100.00	100.00	100.00	100.00	106.25	118.75	131.25	143.75	150.00	150.00	150.00	150.00
	FMM3			FMM4			FMM1			FMM2		
FMM Non-Dispatchable Energy	100.00			108.33			141.67			150.00		
FMM Ramp Award (MW)	8.33			33.33			8.33			0.00		
FMM Ramp Award (MW)	2.78	2.78	2.78	11.11	11.11	11.11	2.78	2.78	2.78	0.00	0.00	0.00
RTD Incremental Ramp Award (MW)	-2.78	-2.78	-2.78	-4.86	1.39	1.39	9.72	3.47	-2.78	0.00	0.00	0.00
Final Ramp	0.0	0.0	0.0	6.25	12.5	12.5	12.5	6.25	0.00	0.00	0.00	0.00

Unlike supply and interties, load cannot be settled directly for forecasted movement with a Scheduling Coordinator (SC) because the ISO load forecast that is used to clear the market is aggregated for each balancing authority area. Therefore, all payments and charges to load based upon the ISO market forecast will be allocated based on load ratio share for each 5-minute settlement interval for each balancing authority area.

7.2 Rescission of payments for FRP awards

Since dispatchable resources, non-dispatchable resources, interties, and load will all be awarded and compensated for FRP, the ISO is proposing a consistent approach to address the potential double payment of opportunity costs. The double payment arises when a resource is awarded FRP and is then subsequently settled for uninstructed imbalance energy. For example, assume a resource's energy bid is $30/MWh and the market clearing LMP was $40. If the resource was awarded FRU, it would be paid no less than $10 for the FRU award. If the resource then deviated above its binding dispatch, the resource would incur positive uninstructed imbalance energy and be paid at the 5-minute LMP of $40. This would result in a profit of $10 which would be the same as the opportunity cost used to compensate the FRU award which assumed the resource would be at it dispatch operating target.

For each settlement interval in which a resource is awarded FRP, the ISO will determine if the resource was double paid by comparing uninstructed imbalance energy (UIE) to the FRP award. If the resource's final meter indicates that the resource has uninstructed imbalance energy deviation or operational adjustment that overlaps with the reserved FRP awarded capacity, the ISO will rescind this portion of the FRP award. The FRP rescission quantity will be charged at the five-minute market FRP price. The FRP rescission quantity will be first assessed against the resource's FRP uncertainty awards and then against the FRP movement awards.

The rescinded FRP amount for forecasted movement will be charged in each settlement interval with the same settlement timing as energy imbalances. The rescinded FRP amount for uncertainty will be charged at the end of the month to eliminate the need for a monthly resettlement since uncertainty costs are allocated monthly.

The rescinded FRP amounts for forecasted movement will be paid to the resources which were directly charged in proration to their forecasted movement in the binding RTD interval. The rescinded FRP amounts for uncertainty will be netted against the FRP uncertainty payments prior to monthly allocation to load, supply, and interties as discussed in the next section.

7.3 Monthly settlement of uncertainty

Unlike forecasted movement, there is no counterparty to directly charge in the financially binding interval for FRP procured for uncertainty. Uncertainty is procured to address the potential for differences in net load when the advisory interval becomes financially binding in the subsequent market run. This difference occurs when uncertainty is realized in a future interval. Since the additional ramping capability is similar to insurance, it is appropriate to not allocate cost for a given realization of uncertainty, but over a period of time. Therefore, the cost (payment to dispatchable resources) will be allocated at the end of the month through an uplift.

The FRP for uncertainty awards will be settled with dispatchable resources at the applicable binding interval FMM or RTD price at the end of the month. The ISO had previously proposed settling these on a daily basis and initially allocating the costs to load and resources according to the relevant billing determinant. By not paying the uncertainty awards immediately, there is no need to perform a monthly resettlement because the payment to a resource and the cost allocation will occur in the same settlement period. This is a significant simplification of the settlements implementation.

In addition, payment rescissions to dispatchable resources for uninstructed imbalance energy that would provide a double payment as discussed in the previous section will be charged at the end of the month. The payment rescission will be settled at applicable binding interval RTD price in which the payment rescission occurred.

To the extent that the sum of the Settlement amounts for Flexible Ramp Up Uncertainty Settlement Amount, Flexible Ramp Down Uncertainty Settlement Amount, Flexible Ramp Up Uncertainty Rescission Amount, Flexible Ramp Down Uncertainty Rescission Amount, Flexible Ramp Up Uncertainty Allocation Amount, and Flexible Ramp Down Uncertainty Allocation Amount does not equal zero, the ISO will assess the resulting differences to all SCs with metered demand within the balancing authority area.

7.3.1 Allocation of uncertainty

The ISO proposes settling the uncertainty for two groups of trade hours. In the assessment of grid management charge (GMC) prior to the 2010 GMC redesign, the ISO identified a GMC bucket for charging load based upon Non-Coincident Peak hours and Non-Coincident Off Peak Hours. Non-Coincident Peak Hours is defined as trading hours ending 7 through 22 for all trading days within a trading month, whereas Non-Coincident Off Peak Hours is defined as trading hours ending 1 through 6 and trading hours 23 through 25 for all trading days within a trading month. For each group of the hour, the FRP for uncertainty uplift cost is the sum of the monthly payments to dispatchable resources less monthly payment rescissions charges to dispatchable resources in the each bucket of trading hours. The total FRP for uncertainty uplift cost is first allocated between the load, supply, and intertie categories. The respective uplift costs allocated to the load, supply, and intertie categories are then allocated to individual resources or loads using a different billing determinate method for each category.

The initial allocation of FRP uncertainty uplift costs between the load, supply, and intertie categories is determined by calculating the "vertical" binding – advisory as shown in figure 10. This difference will be calculated for all non-dispatchable[4] changes in supply resources, interties[5] and load for each 5-minute interval. There is no netting between 5-minute intervals, so in each 5-minute interval there will be either a FRU value or an FRD value. Table 12 below illustrates whether the observed net load error will split FRU or FRD costs. "A" is the advisory interval in the first RTD run and "B" is the binding interval from the second RTD run.

The initial allocation of FRP uncertainty uplift costs between the load, supply, and intertie categories is determined by calculating the "vertical" binding – advisory as shown in Figure 10. This difference will be calculated for all non-dispatchable resources, interties and load for each 5-minute interval. There is no netting between 5-minute intervals, so in each 5-minute interval there will be either a FRU value or an FRD value. Table 12 below illustrates whether the observed net load error will be used to split FRU or FRD costs. "A" is the advisory interval in the first RTD run and "B" is the binding interval from the second RTD run.

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[4] Only non-dispatchable resources can have forecast errors between the two market runs. A dispatchable resource could have differences between the two market runs, but this is in response to market instructions not a result a forecast error of that resources.

[5] Only operational adjustments that occur after RTD initializes will result in a forecast error. Once the operational adjustment is reflected in RTD, it is settled as part of the forecasted movement.

TABLE 12 ALLOCATION OF UNCERTAINTY UPLIFT COSTS BETWEEN FRU AND FRD

	FRU	FRD
Load	A-B > 0	A-B < 0
Supply	A-B < 0	A-B > 0
Interties (Net import in B)	A-B < 0	A-B > 0
Interties (Net export in B)	A-B > 0	A-B < 0

*For load and exports the values of A and B are negative

The load forecast is a single value for each balancing authority area, therefore the forecast error nets errors resulting from individual load serving entities. The load will have a single FRU or FRD value for each settlement interval per balancing authority area based on the ISO forecast between "vertical" advisory – binding interval shown in Figure 10. When splitting the costs into each category, supply and interties must also have a single FRU or FRD value for each settlement interval per balancing authority area. This is accomplished by netting all resources within the supply category and separately netting all intertie schedules within the intertie category to then calculate a single value for each of the categories.

There will be 4 monthly costs that will be allocated: FRU Peak, FRD Peak, FRU Off Peak, and FRD Off Peak. The FRU and FRD values in each 5-minute interval for each category are summed for the month over each range of trading hours. Then each category is allocated its pro-rata share of the monthly FRP costs. The each category allocates its four costs according to its own billing determinant.

1. Load is allocated to each SC based on the pro-rata share of gross UIE over the month. There is no netting between settlement intervals. Negative (increased consumption) UIE is allocated FRU and positive (decreased consumption) UIE is allocated FRD. If a load uses five minute metering, such as load following metered sub-systems, then the load would be included within the supply category.
2. Supply is allocated by calculating the observed forecast error (the vertical advisory – binding) plus any uninstructed imbalance energy. Each resource is allocated its pro-rata share of gross (A-B-UIE) for over the month for each cost bucket. There is no netting between settlement intervals. Positive (A-B-UIE) is allocated FRU and negative (A-B-UIE) is allocated FRD. Uninstructed imbalance energy was included to provide an additional incentive for dispatchable resources to follow their dispatch instruction. If UIE persists, this can increase the need for ramping capability.
3. Intertie category is allocated to each SC based upon the pro-rata share of gross operational adjustment in each cost bucket over the month. Uncertainty costs for interties will be small. The uncertainty is realized only if an operational adjustment occurs after the binding RTD interval prior to the start of the next RTD interval. Otherwise, the operational adjustment will be resettled as a forecasted movement in RTD. Most operational adjustments occur prior to the start of the operating hour and will be settled through the forecasted movement deviation between FMM and RTD.

7.4 Settlement Examples

The examples in tables 13-16 show the energy and FRP settlement for supply, load and interties scheduled for energy and awarded FRP.

Table 13 illustrates the real-time market energy settlement for each resource type for FRU when load is increasing. Generator 1 is awarded 100 MW of FRU but provided an additional 50 MW which was reported by the meter. Therefore, Generator 1 will be paid 100 MW of the FRU award and charged 50 MW as a payment rescission. Generator 2 is awarded 50 MW of FRU uncertainty and 900 MW of FRU movement. The meter showed that Generator 2 produced 75 MW which is 25 MW more than the awarded uncertainty, in which 25 MW will be charged to the generator as a payment rescission. Load is charged 1000 MW of FRU but will also be paid the 75 MW that was rescinded from generators 1 and 2.

Table 14 illustrates the real-time market energy settlement for each resource type for FRU when actual metered load was lower than what was forecasted. In this example, load was forecasted at 1000 MW but the meter showed that it was 150 MW lower than what was forecasted. Load will be paid 1000 MW FRU but charged 150 MW rescission. The generators will be allocated pro-rata share of this 150 MW rescission charge from load. The payment rescission basis for generators 1 and 2 will be the product of the 150 MW that was below forecast and the amount of FRU awarded to the generator divided by the total FRU awarded.

Tables 15 and 16 illustrate the real-time market energy settlement for FRD under the same scenario for load changes. The results of each resource types' awards and rescissions are calculated in a similar manner as tables 13 and 14.

Table 13 Flexible Ramp Up Settlement with Rescission (Load Forecast Increase)

Resource Type	FRU Uncertainty Award (MW)	FRU Movement Award (MW)	Meter – Total Expected Energy or Load Forecast	FRU Uncertainty Rescission Quantity (MW)	FRU Movement Rescission Quantity (MW)	FRU Uncertainty Settlement ($)*	FRU Uncertainty Rescission ($)*	FRU Movement Settlement ($)	FRU Movement Rescission ($)
Gen 1	0	100	50	0	50	0	0	100 MW FRU Payment	50 MW FRU Rescission Charge
Gen 2	50	900	75	50	25	50 MW FRU Payment	50 MW FRU Rescission Charge	900 MW FRU Payment	25 MW FRU Rescission Charge
Import	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Load	0	1000	0			0	0	1000 MW FRU Charge	75 MW FRU Rescission Payment

* FRU Uncertainty Payment and Rescission Charge is netted together over the month and allocated to load, supply, and interties.

TABLE 14 FLEXIBLE RAMP UP SETTLEMENT WITH RESCISSION (LOAD FORECAST DECREASE)

Resource Type	FRU Uncertainty Award (MW)	FRU Movement Award (MW)	Meter – Total Expected Energy or Load Forecast	FRU Uncertainty Rescission Quantity (MW)	FRU Movement Rescission Quantity (MW)	FRU Uncertainty Settlement ($)*	FRU Uncertainty Rescission ($)*	FRU Movement Settlement ($)	FRU Movement Rescission ($)
Gen 1	0	100	0	0	0	0	0	100 MW FRU Charge	150 MW * (100/1000) FRU Rescission Payment
Gen 2	0	900	0	0	0	0	0	900 MW FRU Charge	150 MW * (900/1000) FRU Rescission Payment
Import	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Load	0	1000	150	0	150**	0	0	1000 MW FRU Payment	150 MW FRU Rescission Charge

* FRU Uncertainty Payment and Rescission Charge is netted together over the month and allocated to load, supply, and interties.
** The Actual Meter Load change was less than forecasted.

TABLE 15 FLEXIBLE RAMP DOWN SETTLEMENT WITH RESCISSION (LOAD FORECAST INCREASE)

Resource Type	FRD Uncertainty Award (MW)	FRD Movement Award (MW)	Meter – Total Expected Energy or Load Forecast	FRD Uncertainty Rescission Quantity (MW)	FRD Movement Rescission Quantity (MW)	FRD Uncertainty Settlement ($)*	FRD Uncertainty Rescission ($)*	FRD Movement Settlement ($)	FRD Movement Rescission ($)
Gen 1	0	100	-50	0	50	0	0	100 MW FRD Payment	50 MW FRD Rescission Charge
Gen 2	50	900	-75	50	25	50 MW FRD Payment	50 MW FRD Rescission Charge	900 MW FRD Payment	25 MW FRD Rescission Charge
Import	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Load	0	1000	0			0	0	1000 MW FRU Charge	75 MW FRU Rescission Payment

* FRU Uncertainty Payment and Rescission Charge is netted together over the month and allocated to load, supply, and interties.

TABLE 16 FLEXIBLE RAMP DOWN SETTLEMENT WITH RESCISSION (LOAD FORECAST INCREASE)

Resource Type	FRD Uncertainty Award (MW)	FRD Movement Award (MW)	Meter – Total Expected Energy or Load Forecast	FRD Uncertainty Rescission Quantity (MW)	FRD Movement Rescission Quantity (MW)	FRD Uncertainty Settlement ($)*	FRD Uncertainty Rescission ($)*	FRD Movement Settlement ($)	FRD Movement Rescission ($)
Gen 1	0	100	0	0	0	0	0	100 MW FRD Charge	150 MW * (100/1000) FRD Rescission Payment
Gen 2	0	900	0	0	0	0	0	900 MW FRD Charge	150 MW * (900/1000) FRD Rescission Payment
Import	0	0	0	0	0	0	0	0	0
Export	0	0	0	0	0	0	0	0	0
Load	0	1000	-150	0	150**	0	0	1000 MW FRD Payment	150 MW FRD Rescission Charge

* FRU Uncertainty Payment and Rescission Charge is netted together over the month and allocated to load, supply, and interties.

** The Meter Load change was greater than forecasted.