Technical Bulletin

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Flexible Ramping Constraint

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Addition of a New Flexible Ramping Constraint in the Real Time Pre-dispatch and Real Time Dispatch Process

Executive Summary

The ISO is preparing to implement[1] a new flexible ramping constraint in the real-time, including the Hour-Ahead Scheduling Process (HASP), the real-time unit commitment or pre-dispatch process (RTPD), and the real time dispatch (RTD) process. This new constraint is necessary to address certain reliability and operational issues observed in the ISO's operation of the grid. The ISO has observed that in certain situations reserves and regulation service procured in the real-time (RTPD and HASP) and units committed for energy in the fifteen unit commitment process (RTPD) lack sufficient ramping capability and flexibility to meet conditions in the five minute market interval during which conditions may have changed from the assumptions made during the prior procurement procedures. The ISO's real-time procedures are designed to ensure sufficient capacity is procured to allow for efficient load following during the five minute interval. A fundamental goal of the ISO is to commit resources through its market and produce awards, commitments and dispatches that are feasible and reasonably mitigate for unexpected outcomes. As discussed below, the ISO has observed numerous instances in which awards and commitments are rendered infeasible due to load forecast error, generation variability, intertie changes. These instances pose reliability concerns because to the degree the ISO must re-dispatch resources in the real-time and there is insufficient committed resource flexibility the ISO may be drawing on operating reserves, regulation or on the interconnection. This issue could be addressed in part by the adoption of the flexible ramping constraint, which is designed to ensure that sufficient upward and downward[2] ramping capability of dispatchable resources is committed to enable the real-time dispatch (RTD) to follow load efficiently and reliably over an estimated range of potential variability of net load around the load forecast.

Under the flexible ramping constraint, the RTPD unit commitment and real time dispatch will ensure the availability of a pre-specified quantity of upward and downward five-minute dispatch capability on committed flexible resources, from such capacity not designated to provide regulation or contingency reserves (spinning and non-spinning reserves) and the upward capacity not utilized to meet the load forecast. The ISO will monitor the effectiveness of this new constraint and may in the future consider applying it in the day-ahead market.

[1] A specific date of implementation has not been determined. When a date of implementation is determined advance notice of the specific date will be communicated.

[2] Enforcing downward ramping constraint may not be effective in times of over-supply conditions as commitment of additional resources to be able to ramp down may exacerbate over-supply conditions.

1 Background

1.1 Operational Need for Real-Time Flexibility

IFM, RTPD and RTD optimize resources based on a single imbalance energy forecast amount for an entire interval (hour, 15 minute or 5 minute period, respectively), assuming a perfect load forecast, generation behaving based on dispatch and constant conditions over the interval. There are times IFM and RTPD optimize resources so efficiently that there is little or no additional on-line and available unscheduled capacity for RTD to dispatch for any variation from the constant conditions assumed in IFM and RTPD. The IFM, especially in the peaks and valleys, can optimize resources to meet the average load forecast for the hour, but these resources may not necessarily meet the imbalance for every five minutes within that hour. RTPD does the same thing for the 15 minute period by committing or de-committing resources sufficient to meet the load forecast at the time RTPD is run for a single load forecast but not necessarily good enough for RTD to meet changes between the time RTPD ran and the time RTD runs. In addition, RTPD is dispatching units to meet the average imbalance energy needs for each 15 minutes but not necessarily sufficient to meet the imbalance energy needs for every 5 minute interval within every 15 minutes. This issue is more prominent when the load is increasing in the morning and evening ramps.

Changes in the imbalance energy needs for the RTD after RTPD runs are many and could trigger imbalance shortages especially at peaks and valleys due to short term ramping shortages in RTD. Observed reasons for changes in imbalance energy needs between HASP/RTPD and RTD include:

- Changes in load conditions from forecast[3]
- Differences between average 15 minute imbalance energy needs and 5 minute imbalance energy needs within the 15 minute interval
- Resources shutting down without sufficient notice
- Variable energy resources delivering more or less than forecast
- Contingency events
- High hydro run-off decreasing resource flexibility
- Interties tagging and delivering less than awarded in HASP
- Interchange ramp in and out between hours

When these real-time imbalance energy changes occur and available dispatch ramping capability is exhausted, leaning on regulation or the interconnection, biasing the load and/or Exceptional Dispatch are the only tools left for the operator to deal with this issue. Shortages of ramping capability are an existing operational issue as more intermittent renewable resources are integrated into the ISO system. Figure 1 provides an illustration of conditions that would require additional flexible capability. The figure shows the actual and the forecast demand trajectories for a high ramp-up time period, with a 500 MW shortfall between the actual and the forecast demand.

[3] Load is currently forecasted every 30 minutes with 15 minute forecast being interpolated from the 30 minute forecast. With the launch of ALFS3 the forecasting will be updated every 15 minutes and eventually every 5 minutes.

1.2 Effect of Lack of Flexibility on ISO's Ability to Meet Large Deviations in Net Demand between HASP/RTPD and RTD

The lack of sufficient operational flexibility to respond to the imbalance variability and the uncertain magnitude of differences between expected conditions in RTPD and RTD results in both operational and market impacts. During conditions of real-time imbalance flexibility shortages, the ISO will automatically begin leaning on regulation capacity and available operating reserves that have not been flagged for use only in case of a contingency. If an imbalance shortage persists or is larger than what can be satisfied by available regulation and non-contingency reserves, the ISO may either begin leaning on other Balancing Authority Areas in the interconnection, and/or be forced to dispatch and potentially deplete its operating reserves. If this leaning becomes excessive or the ISO is not able to maintain its operating reserves, the ISO could jeopardize its ability to meet NERC operating criteria and could incur penalties. In the most extreme circumstances, imbalance shortages can result in the ISO being forced to consider firm load curtailment and/or be subject to reliability compliance actions from WECC/NERC. Therefore it is necessary to ensure that the ISO is prepared for varying and uncertain imbalance conditions to operate the grid consistent with prudent utility practice.

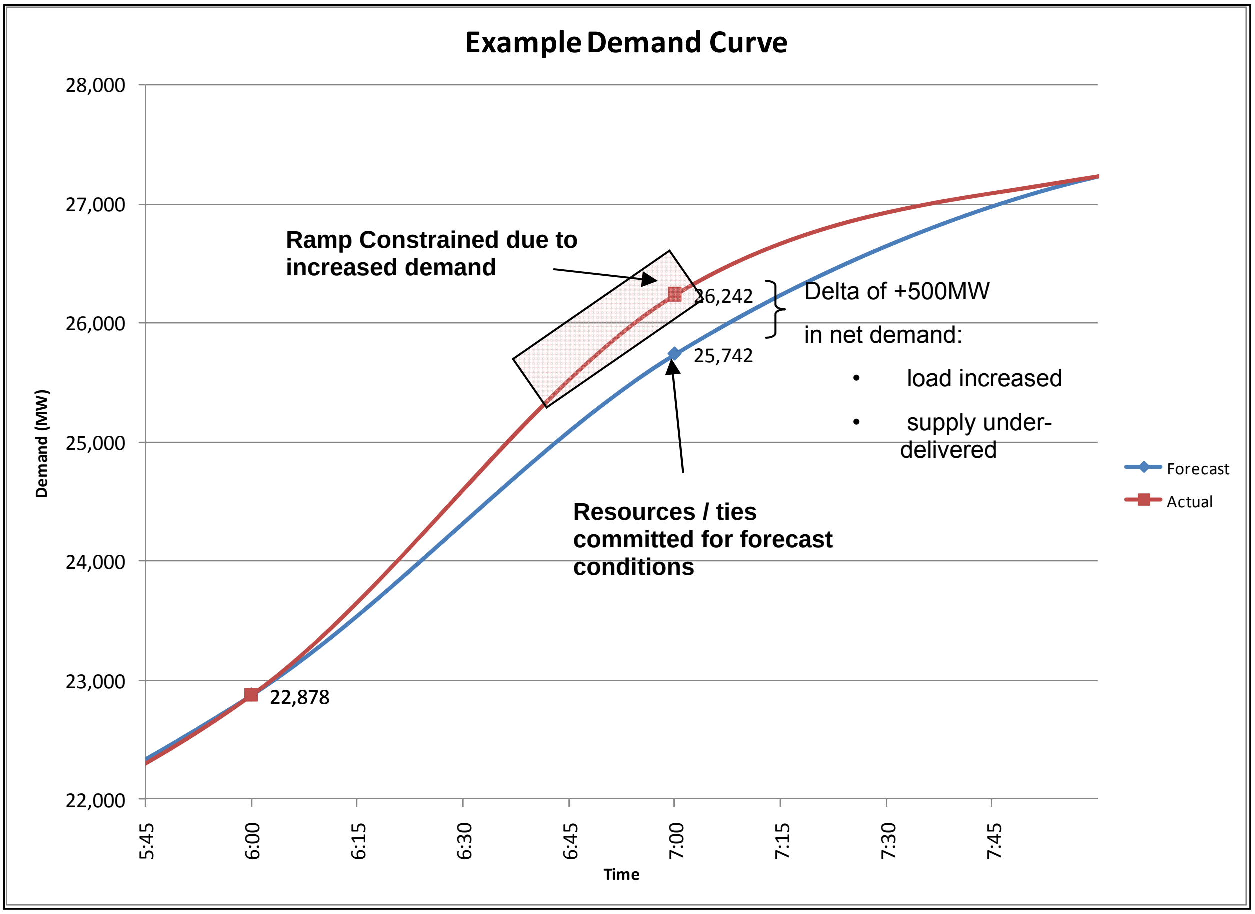

Figure 1: Illustration of Need for flexibility constraint

2 The Flexible Ramp Constraint

The ISO has already implemented several measures to reduce the uncertainty of imbalance conditions expected between HASP and RTD. These measures include: 1) improving consistency between the HASP and RTD forecasts, 2) accounting for hourly intertie ramp when scheduling hourly intertie energy in HASP, 3) improving the real-time load forecasting tools, and 4) providing improved guidance to the operators regarding HASP and real-time load adjustment practices. Although these measures have yielded improvements, alone they do not ensure there is sufficient operational flexibility committed to meet the variability and uncertainty of real-time imbalance conditions.

The flexible ramping constraint utilizes an operator-specified quantity of upward and downward five-minute ramping capability and affects the RTPD/HASP unit commitment and the RTD dispatch for intervals beyond the binding dispatch interval so as to provide for the availability of this capacity for dispatch in the RTD. The flexible dispatch capability constrained to be available as a result of this constraint in RTPD will come from capacity that is not designated to provide regulation or contingency reserve (i.e., spinning or non-spinning reserve), and will not offset the required procurement of those reserves. Rather, this capacity will be available for five-minute dispatch instructions from the RTD, and if dispatched above minimum load will be eligible to set real-time LMP prices subject to other eligibility provisions established in the ISO tariff section 34.19.2.3.

The flexible ramping constraint will provide the online dispatch flexibility to follow net load variation efficiently in the event the actual load is higher or lower than forecast or supply is not responding as expected or instructed. In addition, the use of the flexible ramping constraint will reduce the need to bias the HASP procurement.

The quantity of the flexible dispatch capability will be determined by operators using tools that will estimate: 1) expected level of imbalance variability, and 2) uncertainty due to forecast error, and 3) differences between the hourly, 15 minute average and actual 5 minute load levels. The expected level of historical imbalance variability will consider the statistical pattern of supply variation including expected variation due to scheduled changes in interchange ramp. Uncertainty due to forecast error will also factor in the historical differences between the hour ahead forecast level and the actual load. The ISO will publish the quantity of upward and downward needs used in the constraint for each relevant market process.

3 Appendix 1: Examples

Below are three examples, demonstrating the dispatch and pricing implications from the use of constraints for flexible ramping are formulated. Examples are intended to demonstrate the effect of the flexible ramping modeled in RTPD[4]. For illustration clarify, examples only has 2 generators and 2 intervals. Moreover, for the purpose of illustration only the minimum online flexible ramping upward capacity requirement (MRUC) is enforced and for first interval only.

For each interval, the upward flexible ramping capacity of each resource is subjected to several constraints on an individual resource basis as follows:

- Capacity constraint where the sum generation schedule, ancillary service and the upward flexible ramping capacity is less than or equal to the Pmax
- Up-ramp limitation in MW ramping range per interval[5] that constrains the total of a) the upward flexible ramping capability and b) one-half of the difference between the generation dispatch level of next interval and previous interval.

Examples intended for RTPD show that the MW generation levels in the RTPD binding interval, i.e. first interval, are lowered for those generators that flexible ramping capacity are designated because of the capacity constraint. However, since energy is not settled in RTPD , and in fact, flexible ramping constraints are not enforced in RTD first binding interval, generators with flexible ramping capacity designated in RTPD shall have such capacity utilized for energy dispatch in RTD, meaning that flexible ramping capacity designated in RTPD does not result in generators forgoing opportunity from participating in RTD energy market.

The first example considers a scenario with energy only without any ancillary service. As RTPD considers both energy and AS in the optimization formulation, this energy only example is developed only for purpose of comparing with the next two examples for which AS is considered. The table below illustrates the data.

Generator	1	2
Pmax (MW)	200	200
Energy Bid ($/MW.Interval)	20	25
Initial Condition (MW)	180	180
Ramp Rate (MW/Interval)	30	10

Interval	1	2
Load (MW)	360	360
MRUC (MW)	32	

In this example, generator 1 is fast in ramping and submits a lower bid while generator 2 and slower in ramping and submits a higher bid. Load is 360MW for both intervals. Initially,

[5] The ramping range in this constraint in the design for production is discounted by the AS awards of adjacent intervals using simplified ramping rules. However, for simplicity, no such discount is modeled in the illustrative examples here.

both generators are at 180MW. In order to achieve a solution that minimizes bid cost, the lower bid generator 1 ramps up and vice versa for the higher bid generator 2. However, for the provision of sufficient amount of flexible ramping capabilty to meet the requirement, MW level of generator 1 at interval 1 has to be refrained from moving higher by the capacity constraint of this resource.

In presenting the mathematical equations of the problem, notations of variables and inputs are defined next.

Notations of Variables

G_i^t – MW dispatch level of generator i at interval t where i = 1, 2 and t = 1, 2

PR_i^t – Upward flexible ramping capability of generation i at interval t with t = 1

Notations of Inputs

$Pmax_i$ – Maximum capacity of generator i where i = 1, 2 for both intervals 1 and 2

RR_i – MW ramping range per interval both upward and downward directions

G_i^0 – Initial MW level of generator i where i = 1, 2.

pe_i – Energy bid price of generator i where i = 1, 2 for both intervals 1 and 2

L^t - Load of interval t where t = 1, 2

$MRUC^t$ – Minimum online ramping upward capability requirement of interval t with t = 1

Objective function for minimization:

$pe_1 * (G_1^1 + G_1^2) + pe_2 * (G_2^1 + G_2^2)$

Equations of constraints:

The following table shows the equations. For clarity, constraints having no bearings to the final solution of this problem are omitted.

Eq #	Description	Equation Formula		
		LHS	Relationship	RHS
1	Power balance at T1	$G_1^1 + G_2^1$	=	L^1
2	Power balance at T2	$G_1^2 + G_2^2$	=	L^2
3	MRUC requirement at T1	$PR_1^1 + PR_2^1$	≥	$MRUC^1$
4	Capacity Constraint of G_1 at T1	$G_1^1 + PR_1^1$	≤	$Pmax_1$
5	Up-ramp constraint on G_1 flexible ramping capability at T1	$0.5 * G_1^2 + PR_1^1$	≤	$RR_1 + 0.5 * G_1^0$
6	Up-ramp constraint on G_1 generation from initial time to T1	G_1^1	≤	$RR_1 + G_1^0$
7	Up-ramp constraint on G_1	$G_1^2 - G_1^1$	≤	RR_1

	generation from T1 to T2			
8	Capacity Constraint of G_2 at T1	$G_2^1 + PR_2^1$	≤	$Pmax_2$
9	Up-ramp constraint on G_2 flexible ramping capability at T1	$0.5*G_2^2 + PR_2^1$	≤	$RR_2 + 0.5*G_2^0$
10	Down-ramp constraint on G_2 generation from initial time to T1	G_2^1	≥	$-RR_2 + G_2^0$
11	Down-ramp constraint on G_2 generation from T1 to T2	$G_2^2 – G_2^1$	≥	$-RR_2$

The minimum bid cost solution is shown next.

G_1^1	G_2^1	PR_1^1	PR_2^1	G_1^2	G_2^3
186MW	174MW	14MW	18MW	196MW	164MW

The following table indicates the constraints that are binding as well as their shadow prices. Shadow price of a binding constraint is the change in bid cost per unit increase of the RHS value of the constraint. Shadow price is zero for constraint not binding.

Eq #	Description	Binding Sts	Shadow Price	RHS Value
1	Power balance at T1	Y	40	360
2	Power balance at T2	Y	20	360
3	MRUC requirement at T1	Y	20	32
4	Capacity Constraint of G_1 at T1	Y	-20	200
5	Up-ramp constraint type 1 on G_1 flexible ramping capability at T1	N	0	120
6	Up-ramp constraint on G_1 generation from initial time to T1	N	0	210
7	Up-ramp constraint on G_1 generation from T1 to T2	N	0	30
8	Capacity Constraint of G_2 at T1	N	0	200
9	Up-ramp constraint on G_2 flexible ramping capability at T1	Y	-20	100
10	Down-ramp constraint on G_2 generation from initial time to T1	N	0	190
11	Down-ramp constraint on G_2 generation from T1 to T2	Y	15	-10

Without the MRUC requirement, generator 1 is scheduled at 190MW and 200MW for intervals 1 and 2. Generator 2, the slower ramping resource is scheduled at 170MW and 180MW for the two intervals, continuous to ramp down at ramp rate limit throughout the entire 2-interval horizon.

However, with MRUC requirement enforced, generator 1 can only ramp up from initial 180MW to 186MW for providing 14MW of flexible ramping capability limited by the binding capacity constraint the generator. In the meantime, generator 2 is scheduled at 174MW for interval 1 for power balancing. It further ramps down at ramp limit to 164MW at interval 2 with generator 1 at 176MW for power balancing. Generator 2 contributes 18MW flexible ramping capability at interval 1, limited by the binding up-ramp constraint of flexible ramping capability. The total contributions in flexible ramping capability is 32MW, meeting the MRUC requirement exactly.

The energy price at interval 2 is $20 and is set by generator 1. The energy price at interval 1 is $40 which is the increase in system cost per MW increase in load for this interval. How it is determined is somewhat non-trivial. For 1MW increase in load at interval 1, all six variables are adjusted to maintain power balance for both intervals and the satisfying of the MRUC requirement at interval 1. The adjusted values of variables through solving the binding constraint equations are

G_1^1	G_2^1	PR_1^1	PR_2^1	G_1^2	G_2^3
185MW	176MW	15MW	17MW	194MW	166MW

The change in system cost associated with the new values of variables is $40, yielding the energy price of interval 1.

The shadow price of the MRUC constraint at interval 1 is $20 which is the increase in system cost per MW increase in MRUC requirement. Such an increase in MRUC requirement in conjunction with maintaining the power balancing for both intervals can only be met by the adjustments in variables to the following new values through solving the binding constraint equations.

G_1^1	G_2^1	PR_1^1	PR_2^1	G_1^2	G_2^3
184MW	176MW	16MW	17MW	194MW	166MW

The change in system cost associated with the new values of variables is $20, yielding the shadow price of the MRUC constraint. This shadow price is also the opportunity cost of generator 1 in providing per MW of flexible ramping capability. Under the binding of the capacity constraint of generator 1, each MW provision of flexible ramping capability will result in forfeiting the $20 profit from using this capacity to generate where the $20 profit is the difference between the $40 energy price of interval 1 and the $20 bid of this generator.

In conclusion, the inclusion of flexible ramping constraints in the optimization formulation will change the MW dispatch levels of generators and influences the energy price. The shadow price of MRUC requirement constraint, when non-zero, is simply the opportunity cost account for the profit on per MW basis that generator forgoes because it is not able to generate for energy sale under the provision of flexible ramping capability. However,, the energy dispatches and prices resulting in RTPD are not relevant to the opportunity cost since no binding energy settlement occurs in RTPD.

The second example considers ancillary service requirement for only interval 1 with all other requirements and data identical to the previous example. AS requirement is 5MW. Only generator 1 submits AS bid at $2/MW.Interval. AS_1^1 denotes the AS variable of generator 1 at interval 1. Constraints are all the constraints from previous example with the addition of the minimum AS requirement for interval 1. With objective function including the bid cost of AS, the minimum bid cost solution is presented next.

G_1^1	G_2^1	AS_1^1	PR_1^1	PR_2^1	G_1^2	G_2^3
176	184	5	19	13	186	174

In order to reserve additional capacity from generator 1 for 5MW AS while meeting all other requirements, generation of generator 1 is reduced below its initial condition of 180MW to 176MW at interval 1. Starting from solution of the previous example, with 1MW decrease in generation from generator 1 at interval 1 (and interval 2), 1 MW additional unload capacity is made available as governed by the binding capacity constraint. On the other hand, the power balancing by 1MW increase of generation from generator 2 for both intervals will result in 0.5MW reduction in flexible ramping capability governed by the binding up-ramp constraint. This explains how the solution is arrived from the 10MW generation adjustment of generator 1 upward and generator 2 downward for both intervals from solution of previous example.

All the constraints that are binding in the solution of previous example are also binding here. Shadow prices of these constraints are identical for both examples. Additionally, the AS requirement constraint is binding in this example. As expected, shadow price of this constraint is $22 which is the $2 bid price plus the $20 opportunity cost from forgoing profit because of capacity reserved for AS not able to generate energy. Both the shadow prices of the MRUC requirement and AS requirement constraints have this $20 opportunity cost component from energy.

The third example also considers ancillary service requirement for only interval 1. With MRUC requirement reduced from 32MW to 27MW and generator 2 submitting an AS bid at $6/MW.interval, all other requirements and data identical to the second example. AS_i^1 denote the AS variables of generator i at interval 1 where i = 1, 2. Constraints are the same as example 2. With objective function including the bid cost of AS of generators 1 and 2, the minimum bid cost solution is presented next.

G_1^1	G_2^1	AS_1^1	AS_2^1	PR_1^1	PR_2^1	G_1^2	G_2^3
190	170	3	2	7	20	200	160

The following table indicates the constraints that are binding as well as their shadow prices.

Eq #	Description	Binding Sts	Shadow Price	RHS Value
1	Power balance at T1	Y	24	360

2	Power balance at T2	Y	20	360
3	MRUC requirement at T1	Y	4	27
4	Capacity Constraint of G_1 at T1	Y	-4	200
5	Up-ramp constraint type 1 on G_1 flexible ramping capability at T1	N	0	120
6	Up-ramp constraint on G_1 generation from initial time to T1	N	0	210
7	Up-ramp constraint on G_1 generation from T1 to T2	N	0	30
8	Capacity Constraint of G_2 at T1	N	0	200
9	Up-ramp constraint on G_2 flexible ramping capability at T1	Y	-3	100
10	Down-ramp constraint on G_2 generation from initial time to T1	y	8	190
11	Down-ramp constraint on G_2 generation from T1 to T2	Y	7	-10
12	AS requirement at T1	Y	6	5

Generator 2, the higher bid resource, is ramped down from initial condition at its ramp limit throughout the entire 2-interval horizon for cost minimization. Generator1, the lower bid resource is ramped up at the same rate for power balance. The energy price of interval 2 is $20 and is set by generator 1. AS price of interval 1 is $6 and is set by generator 2. The energy price of interval 1 is $24 which is the $20 bid price of generator 1 plus $4 opportunity cost arising from using this generator capacity for energy rather than AS for lower bid cost solution. Similar the shadow price of the MRUC requirement is $4 which is also the opportunity cost from AS.

The ISO will consider incorporating such opportunity cost in a phase-in process. First, the constraint will be introduced to better understand the constraint and its effectiveness. Second, the ISO will evaluate whether it is appropriate to provide compensation for opportunity costs for specific resources if it is determined resources are forgoing settlement opportunities for energy or other ancillary services in order to provide ramping capability. Third, the ISO will continue to consider specifications of new products as part of the ISO's Renewable Integration Market and Product Review Phase 2 effort.