California ISO
Shaping a Renewed Future

Supplemental Examples for the Technical Workshop on Flexible Ramping Products

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Meet ramping needs with flexible ramping product

- Ramping needs should be evaluated over various time frames
  - 60 minutes, 15 minutes and 5 minutes
  - Do we have to define three ramping products?
    - The 60-minute ramping product, a.k.a. load following
    - The 15-minute ramping product
    - The 5-minute ramping product
- Flexible ramping product
  - A single 5-minute ramping product
  - Meet ramping needs of different time frames by averaging the 5-minute ramping capability over the time horizon
    - In DA, average over an hour, value hourly ramping capability
    - In RTUC, average over 15 minutes, value 15-minute ramping capability
    - In RTD, average over 5 minutes, value 5-minute ramping capability

Flexible ramping product award and settlement

- How much a resource can be awarded?
  - Ramp constraint:
    - FRU <= 5*ramp_rate, FRD <= 5*ramp_rate

    (define ramp constrained resource as resource with binding ramping constraint. It is typically a slower ramping resource.)
  - Capacity constraint:
    - MCG/5*FRU <= Pmax – En, MCG/5*FRU <= En – Pmin

    (define capacity constrained resource as resource with binding capacity constraint. It is typically a faster ramping resource.)

    Where MCG is the market clearing granularity
    - For RTD, MCG = 5 minutes
    - For RTUC, MCG = 15 minutes
    - For DA, MCG = 60 minutes
- How a flexible ramping award is settled for a clearing interval?
  - Upward: P^{FRU}*FRU*MCG/60
  - Downward: P^{FRD}*FRD*MCG/60

FRP award and settlement example 1

- Ramp constrained resource example:
  - Assume resource A has Pmax = 700 MW, En = 100 MW, ramp rate = 10 MW/minute in DA, RTUC and RTD
  - In RTD, FRU_A = min{5*10, (700-100)/(5/5)} = 50 MW for 12 5-minute intervals
  - In RTUC, FRU_A = min{5*10, (700-100)/(15/5)} = 50 MW for 4 15-minute intervals
  - In DA, FRU_A = min{5*10, (700-100)/(60/5)} = 50 MW for an hour
- Settlement:
  - Assume the flexible ramping price is the same in DA, RTUC, and RTD: $1/MWh
  - If resource A is only awarded flexible ramping in RTD (12 intervals = 1 hour), it will get paid (1*50*5/60)*12 = $50
  - If resource A is only provides flexible ramping headroom in RTUC (4 intervals = 1 hour), there will be no settlement
  - If resource A is only awarded flexible ramping in DA (1 hour), it will get paid (1*50*60/60) = $50

FRP award and settlement Example 1 continued

- What if resource A's ramping is being utilized in RTD
  - RTD energy dispatch En = 100, 150, 200, …, 650
  - RTD flexible ramping award is still FRU_A = 50 MW for 12 5-minute intervals
- Settlement:
  - Assume the flexible ramping price is $1/MWh in RTD
  - In RTD, resource A is paid (1*50*5/60)*12 = $50
- Ramp constrained resource's flexible ramping award only depends on the ramp rate, so utilizing the flexible ramping capacity in RTD will not impact the flexible ramping capability in the subsequent intervals.

FRP award and settlement Example 2

- Capacity constrained resource example:
  - Assume resource B has Pmax = 700 MW, En = 100 MW, ramp rate = 150 MW/minute
  - In RTD, FRU_B = min{5*150, (700-100)/(5/5)} = 600 MW for 12 5-minute intervals
  - In RTUC, FRU_B = min{5*150, (700-100)/(15/5)} = 200 MW for 4 15-minute intervals
  - In DA, FRU_B = min{5*150, (700-100)/(60/5)} = 50 MW for an hour
- Settlement:
  - Assume the flexible ramping price is the same in DA, RTUC, and RTD: $1/MWh
  - If resource B is only awarded flexible ramping in RTD (12 intervals = 1 hour), it will get paid (1*600*5/60)*12 = $600
  - If resource B only provides flexible ramping headroom in RTUC (4 intervals = 1 hour), there will be no settlement
  - If resource B is only awarded flexible ramping in DA (1 hour), it will get paid (1*50*60/60) = $50

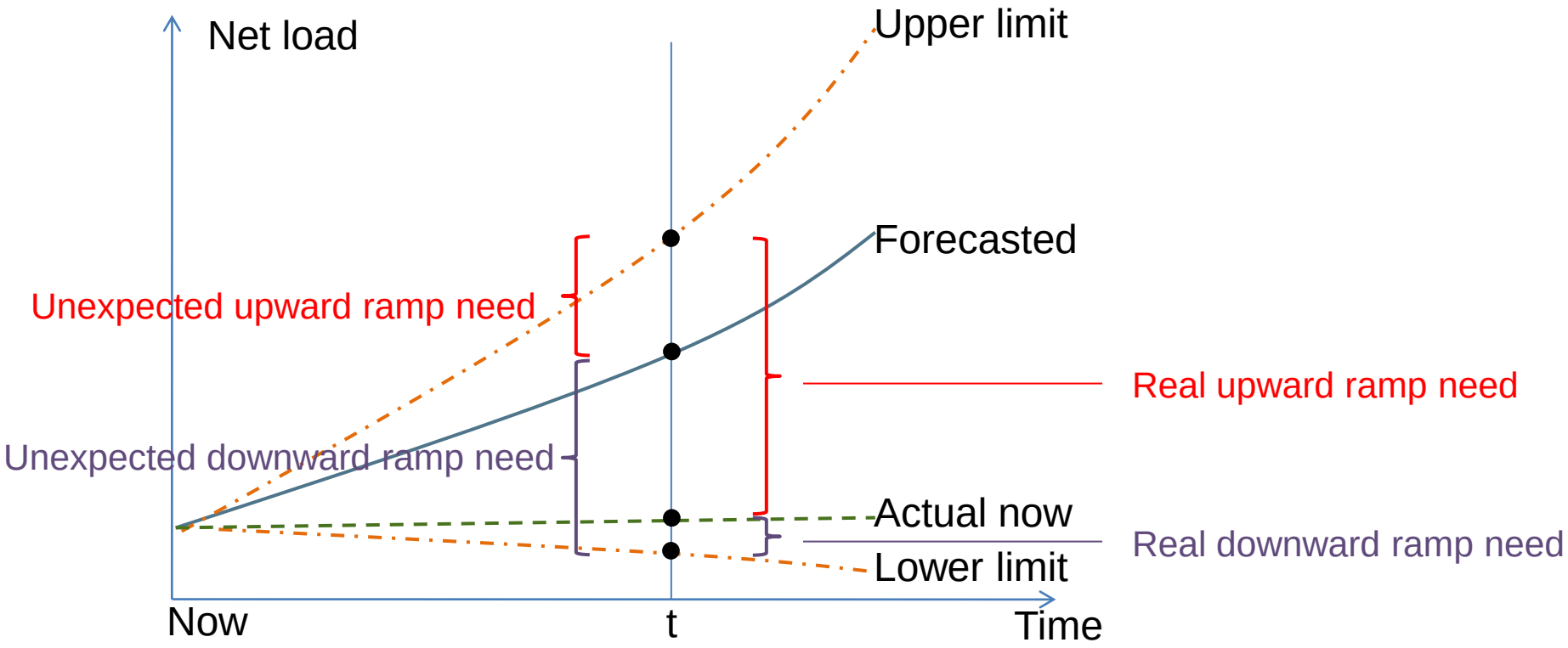
FRP award and settlement Example 2 continued

- What if resource B's ramping is being utilized in RTD
  - RTD energy dispatch En = 100, 700, 700, …, 700
  - RTD flexible ramping award is FRU_B = 600 MW for the first 5-minute interval of the hour, and FRU_B = 0 MW for the rest 11 intervals of the hour
- Settlement:
  - Assume the flexible ramping price is $1/MWh in RTD
  - In RTD, resource B is paid (1*600*5/60)*1+ (1*0*5/60)*11 = $50
- Capacity constrained resource's flexible ramping award depends on the market clearing granularity. The RTD award is equal to the DA award over the entire hour if the ramping capability is used up in one interval. If the ramping capability is not used up in one interval, the RTD award over the hour can be higher than DA award (up to 12 times of the DA award).

Observations from the FRP award examples

- Flexible ramping product is 5-minute ramping capability product, the 5-minute ramping capability will be evaluated/averaged over the length of the market clearing interval.
- Economic ramp constrained resource (assuming the save energy dispatch level initially)
  - The same award amount in DA, RTUC, and RTD
  - If it receives full DA award, there cannot be additional real-time award/headroom
- Economic capacity constrained resource (assuming the save energy dispatch level initially)
  - Likely different award/headroom amount in DA, RTUC, and RTD
  - RTUC headroom is between 1 and 3 times of the DA award
  - RTD award is between 1 and 12 times of the DA award
  - If it receives full DA award, it can still get extra award in real-time. This is how the value of faster resource gets recognized in real-time.

What kind of ramping need does the product address?



Option 1: unexpected ramping
the net load variability and uncertainties from what have been forecasted

Option 2: real ramping
Potential net load change from the current net load

To achieve the same market performance, the sum of the upward and the downward requirement is the same under either option, but how they split differs

Comparing the procurement in the explicit approach and the implicit approach

Explicit (**Meet RTUC unexpected ramping**)

- DA – up X^{60}, down Y^{60}
- RTUC – up RX^{95}, down RY^{95}
- RTD – up min{X^{95}, RX^{95} – R}, down max{Y^{95}, RY^{95} – R}

$[Y^{95}, X^{95}]$ is the 95% confidence interval for 5-minute net load variation between intervals

$[Y^{60}, X^{60}]$ is the 60% confidence interval for 5-minute net load variation between intervals

R = RTD net load – RTUC net load

$[RY^{95}, RX^{95}]$ is the 95% confidence interval for R

Implicit (**Meet real ramping**)

- DA – up $f(\cdot)$, down $g(\cdot)$
- RTUC – up $f(\cdot)$, down $g(\cdot)$
- RTD – up $f(\cdot)$, down $g(\cdot)$

$f(\cdot)$ is the upward flexible ramping demand curve

$g(\cdot)$ is the downward flexible ramping demand curve

Although the demand functions can be used in DA, RTUC and RTD, the actual procurement amount are generally different

Example – explicit target

- RTD: Historical RTD net load
- Delta5: RTD net load at t+5 minus RTD net load at t
- RTUC: historical RTUC net load
- RTD-RTUC: RTD net load minus RTUC net load

$[Y^{95}, X^{95}]$ is the 95% confidence interval for Delta5
$[Y^{60}, X^{60}]$ is the 60% confidence interval for Delta5
$[RY^{95}, RX^{95}]$ is the 95% confidence interval for RTD-RTUC

RTD	Delta5	RTUC	RTD-RTUC
900	110	1005	-105
1010	110	1005	5
1120	30	1005	115
1150	-100	975	175
1050	-90	975	75
960	-60	975	-15
900	-30	903	-3
870	40	903	-33
910	70	903	7
980	120	1106	-126
1100	50	1106	-6
1150	10	1106	44
1160	30	1206	-46
1190	10	1206	-16
1200	-20	1206	-6
1180	-30	1162	18
1150	-40	1162	-12
1110	10	1162	-52
1120			
Y60	-36		
X60	62		
Y95	-96	RY95	-117
X95	116	RX95	150

Example – explicit target continued

Y60	-36				
X60	62				
Y95	-96	RY95	-117		
X95	116	RX95	150		
RTD	Delta5	RTUC	RTD-RTUC	RTD_DN	RTD_UP
…	…	…	…	…	…
1120	30	1158	-38	-79	116
1150	40	1158	-8	-96	116
1190	60	1158	32	-96	116
1250					
…	…	…	…	…	…

RTD_DN: RTD downward flexible ramping requirement

RTD_UP: RTD upward flexible ramping requirement

Max{– 96, – 117 –(– 38)} = – 79 Min{116,150 – (– 38)} = 116

Max{– 96, – 117 –(– 8)} = – 96 Min{116,150 – (– 8)} = 116

Max{– 96, – 117 – 32} = – 96 Min{116,150 – 32} = 116

Example – implicit target

Wrong question: "What is the requirement?"

Correct question: "What is the demand at $30/MWh?" or "How much demand is willing to pay for 300MW of flex ramp?"

- Power balance violation probability
  - 0 – 100 MW, 0.3%
  - 100 – 200 MW, 0.2%
  - 200 – 300 MW, 0.1%
- Power balance violation penalty $1000/MWh
- Load exposure 3,000 MW (about 10% of peak load)
- Flexible ramping demand curve
  - 0 - 100 MW, 3000*1000*0.3%/100 = $90/MWh
  - 100 – 200 MW, 3000*1000*0.2%/100 = $60/MWh
  - 200 – 300 MW, 3000*1000*0.1%/100 = $30/MWh
- Use the same flexible ramping demand curve in DA, RTUC and RTD
  - The demand curve does not only set the procurement target, but also governs how much capacity to release for dispatch

Dispatch flexible ramping capability in RTD

- Release flexible ramping capacity for dispatch
  - Where is the base line?
    - The explicit approach: the base line is the RTUC advisory headroom
    - The implicit approach: the base line is the previous RTD flexible ramping award
- Explicit approach
  - Released amount = RTUC headroom minus RTD requirement
  - Release amount depends on the realized net load imbalance in RTD, i.e. RTD net load minus RTUC net load
- Implicit approach
  - Released amount = RTD procured amount at t minus RTD procured amount at t-1
  - Released amount depends the demand curve and the flexible ramping price difference between interval t-1 to interval t

RTD dispatch example (single interval) – explicit approach

RTD imbalance realizations and requirements

		RTUC1			RTUC2			RTUC3
		RTD1	RTD2	RTD3	RTD4	RTD5	RTD6	RTD7
	RTUC net load	335	335	335	340	340	340	350
	RTD net load	345	325	335	350	400	390	400
upward	RTUC requirement	50	50	50	50	50	50	50
	15 minute bound	40	60	55	40	-10	10	
	5 minute bound	50	50	50	50	50	50	50
	RTD requirement	40	50	50	40	-10	10	
downward	RTUC requirement	40	40	40	40	40	40	40
	15 minute bound	50	30	35	50	100	80	
	5 minute bound	40	40	40	40	40	40	40
	RTD requirement	40	30	35	40	40	40	

Consider RTD4:
- RTUC requires 50 MW headroom
- Realized imbalance is 10 MW
- Upward RTD requirement is 40 MW
- Downward RTD requirement is 40 MW

Compared with RTUC2, RTD4 released 10 MW upward headroom for dispatch, which equals the realized imbalance = RTD net load – RTUC net load = 10 MW

RTD dispatch example (single interval) – explicit approach

Resources

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	25	10	10	10	10	1.4	1.4	20	0	0	0	0	0	10
G2	30	1.1	1.2	0	0	4	4	180	10	10	0	0	10	0
G3	35	3	3	0	0	3	3	89	10	0	0	0	0	0
G4	50	2	2	0	0	2.3	2	10	0	0	0	0	5	0
G5	53	No	No	No	No	SS	SS	30	0	0	0	0	30	30
G6	60	No	No	SS	No	No	No	1	0	0	9	0	0	0

EN – energy
RU – regulation up
RD – regulation down
SP – spinning reserve
NS – non-spinning reserve
FRU – flexible ramping up
FRD – flexible ramping down
No – no bid
SS – self schedule/provision

gen	Pmin	Pmax	operational ramp rate	regulation ramp rate
G1	10	45	5	5
G2	10	200	3	3
G3	10	300	1	1
G4	10	21	8	8
G5	5	65	6	6
G6	1	10	1	1

Requirements

- Load 350 MW
- Upward flexible ramping 40 MW
- Downward flexible ramping 40 MW

RTD dispatch example (single interval) – explicit approach

RTD dispatch and flexible ramping award

gen	Energy	Lower operating limit	Upper operating limit	Flex-ramp up	Flex-ramp down
G1	45	10	45		25
G2	185	20	185		
G3	94	10	290		5
G4	15	10	20	5	5
G5	10	5	65	30	5
G6	1	1	6	5	

Product	Marginal Price ($/MWh)
Energy	50
Upward flexible ramping product	3.3
Downward flexible ramping product	4

Compared with RTUC2, RTD4 released 10 MW upward headroom for dispatch, which equals the realized imbalance = RTD net load – RTUC net load = 10 MW

The 10 MW comes from G2 (5 MW) and G4 (5 MW), both of which are capacity constrained. To confirm, see table 7 in the third revised straw proposal.

RTD dispatch example (single interval) – implicit approach

- Scenario 1
  - Upward demand curve
    - 0-10 MW, $10
    - 10-20 MW, $8
    - 20-30 MW, $6
    - 30-40 MW, $4
    - 40-50 MW, $2.5
  - Downward demand curve
    - 0-40 MW, $4
  - RTUC headroom
    - Upward 50 MW
    - Downward 40 MW
- Scenario 2
  - Upward demand curve
    - 0-10 MW, $10
    - 10-20 MW, $8
    - 20-30 MW, $6
    - 30-40 MW, $3
    - 40-50 MW, $2.5
  - Downward demand curve
    - 0-40 MW, $4
  - RTUC headroom
    - Upward 50 MW
    - Downward 40 MW

The demand curves are constructed in such a way that they produce the exactly the save advisory RTUC dispatch and headroom as the explicit approach.

RTD dispatch example (single interval) – implicit approach

RTD award under scenario 1

gen	Energy	Lower operating limit	Upper operating limit	Flex-ramp up	Flex-ramp down
G1	45	10	45		25
G2	185	20	185		
G3	94	10	290		5
G4	15	10	20	5	5
G5	10	5	65	30	5
G6	1	1	6	5	

Compared with RTD3, RTD4 released 10 MW upward headroom for dispatch. This produces the same results as the explicit approach because the demand price for the demand below 40 MW is $4 > $3.3, and the demand price for demand above 40 MW is $2 < $3.3.

Product	Marginal Price ($/MWh)
Energy	50
Upward flexible ramping product	3.3
Downward flexible ramping product	3

The marginal value of the upward flexible ramping is $3.3. One more MW of FRU will be met by
G4: +1 FRU @ $2.3, -1 EN @ $50, -1 FRD @$2
G5: +1 EN @ $53, +1 FRD @ $0

The amount of flexible ramping demand at price = $3.3 is 40 MW, which is 10 MW lower than the RTUC FRU demand 50 MW.

RTD dispatch example (single interval) – implicit approach

RTD award under scenario 2

gen	Energy	Lower operating limit	Upper operating limit	Flex-ramp up	Flex-ramp down
G1	45	10	45		25
G2	185	20	185		
G3	94	10	290		5
G4	20	10	20		10
G5	5	5	65	30	
G6	1	1	6	5	

Compared with RTD3, RTD4 released 15 MW upward headroom for dispatch. The 15 MW comes from G2 (5 MW) and G4 (10 MW).

Product	Marginal Price ($/MWh)
Energy	49.7
Upward flexible ramping product	3
Downward flexible ramping product	3

The marginal value of the upward flexible ramping is $3. This is set by the demand curve because the demand is between 30 to 40 MW at $3. One more MW of FRU supply would cost $3.3 (from G4), and that is why G4 is not awarded FRU as the demand is only willing to pay $3.

Observations from the RTD dispatch examples

- Both the explicit approach and the implicit approach are heuristic ways to make a decision on how much flexible ramping capability to use and to keep
  - The key to the explicit approach is how to set the RTD requirement based on the realized imbalance
  - The key to the implicit approach is the demand curve
- In the explicit approach, the FRP price can only set by supply, while in the implicit approach, the FRP price can be set either by supply or demand
- If the demand curve price is higher than the shadow price in the explicit approach for demand below the explicit requirement and lower for demand above the explicit requirement, then the implicit approach will produce the same result as the explicit approach, otherwise, generally speaking, the two approaches will produce different results