

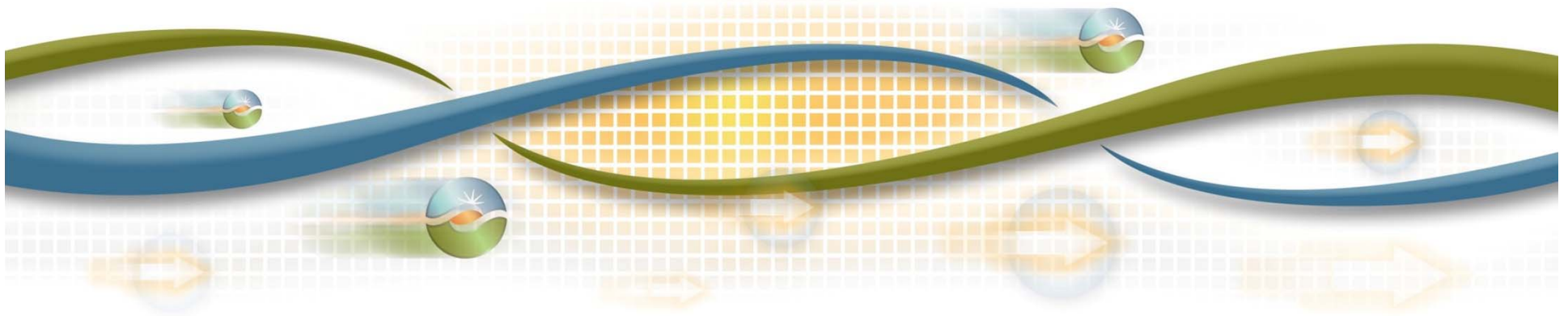


California ISO  
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# Flexible Ramping Product Examples

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## Demonstrate flex ramp interactions

- Multi-interval optimization
- Interactions between RTUC and RTD
- Interactions between RTDs
  - Using the solution from one RTD optimization as the initial condition for the next RTD optimization assuming resources perfectly follow instruction
- Two examples
  - Example 1: flex ramp price set by capacity limited resource
  - Example 2: flex ramp price set by capacity not limited resource

## Example 1 RTUC input

Gen	Online	En bid	FRP bid	En 6:47	Ramp rate	Pmin	Pmax
G1	6:00–10:00	25	0	400	100	0	500
G2	6:00–10:00	30	0	0	10	0	500
G3	6:00–10:00	36	12	0	60	0	300
G4	7:15–9:00	50	0	0	100	0	500

Interval	Net system demand	Lower limit	Upper limit	FRU requirement	FRD requirement
7:00–7:15	500	n/a	n/a	510	0
7:15–7:30	799	700	1010	510	0

Flex ramp demand price \$20.

## Example 1 RTUC solution

	7:00–7:15		7:15–7:30	
Gen	En	FRU	En	FRU
G1	140	360	500	0
G2	150	150	299	150
G3	210	0	0	0
G4	0	0	0	500
Price	\$36	\$11	\$30	\$0

\$11 set by G1's opportunity cost =  
 $LMP - G1's\ En\ bid = 36 - 25 = 11$ .  
 This is cheaper than G3's FRU bid \$12.

G1 is capacity limited. In order to provide FRU, it is dec'ed from its initial energy schedule 400 MW in interval 7:00–7:15.

G2 is ramp limited. It can provide 150 MW over 15 minutes.

## Example 1 RTD1 input

Gen	Online	En bid	FRP bid	En 6:57	Ramp rate	Pmin	Pmax
G1	6:00–10:00	25	0	350	100	0	500
G2	6:00–10:00	30	0	50	10	0	500
G3	6:00–10:00	36	12	0	60	0	150
G4	7:15–9:00	50	0	0	100	0	500

G3 is derated after RTUC.

Interval	Net system demand	Lower limit	Upper limit	FRU requirement	FRD requirement
7:00–7:05	400	n/a	n/a	170	0
7:05–7:10	500	450	570	240	0
7:10–7:15	600	550	740	310	0

Flex ramp demand price \$20.

## Example 1 RTD1 solution

	7:00–7:05		7:05–7:10		7:10–7:15	
Gen	En	FRU	En	FRU	En	FRU
G1	300	200	310	190	250	250
G2	100	50	150	50	200	50
G3	0	0	40	0	150	0
G4	0	0	0	0	0	0
Price	\$25	\$0	\$36	\$11	\$45	\$20

\$20 set by flex ramp demand curve.  
10 MW relaxation.

In order to provide flex ramp for the future (7:05 to 7:15), G1 is dispatched down in the first interval. This creates more \$0 ramping capability than the requirement, and results in \$0 flex ramp price.

## Example 1 RTD2 input

Gen	Online	En bid	FRP bid	En 7:02	Ramp rate	Pmin	Pmax
G1	6:00–10:00	25	0	300	100	0	500
G2	6:00–10:00	30	0	100	10	0	500
G3	6:00–10:00	36	12	0	60	0	150
G4	7:15–9:00	50	0	0	100	0	500

Interval	Net system demand	Lower limit	Upper limit	FRU requirement	FRD requirement
7:05–7:10	500	n/a	n/a	240	0
7:10–7:15	600	550	740	310	0
7:15–7:20	700	650	910	380	0

Flex ramp demand price \$20.

Assume lower limit and upper limit are not changed from RTD1 in this example. In reality, they can be updated.

## Example 1 RTD2 solution

	7:05–7:10		7:10–7:15		7:15–7:20	
Gen	En	FRU	En	FRU	En	FRU
G1	310	190	250	250	500	0
G2	150	50	200	50	200	50
G3	40	0	150	0	0	0
G4	0	0	0	0	0	500
Price	\$36	\$11	\$45	\$20	\$30	\$0

In this example, the upper limit curve and lower limit are not changed from RTD1 to RTD2, the RTD2 optimization produces the same solution for interval 7:05–7:10 and 7:10–7:15 as RTD1 optimization.



## Example 1 RTD3 input

Gen	Online	En bid	FRP bid	En 7:02	Ramp rate	Pmin	Pmax
G1	6:00–10:00	25	0	300	100	0	500
G2	6:00–10:00	30	0	100	10	0	500
G3	6:00–10:00	36	12	0	60	0	150
G4	7:15–9:00	50	0	0	100	0	500

Interval	Net system demand	Lower limit	Upper limit	FRU requirement	FRD requirement
7:10–7:15	600	n/a	n/a	310	0
7:15–7:20	700	650	910	380	0
7:20–7:25	800	750	1080	450	0

Flex ramp demand price \$20.

Assume lower limit and upper limit are not changed from RTD2 in this example. In reality, they can be updated.

## Example 1 RTD3 solution

	7:10–7:15		7:15–7:20		7:20–7:25	
Gen	En	FRU	En	FRU	En	FRU
G1	250	250	450	50	500	0
G2	200	50	250	50	300	50
G3	150	0	0	0	0	0
G4	0	0	0	500	0	500
Price	\$45	\$20	\$25	\$0	\$35	\$0

In this example, the upper limit curve and lower limit are not changed from RTD1 to RTD2 to RTD3, the RTD3 optimization produces the same solution for interval 7:10–7:15 as RTD1 optimization and RTD2 optimization.

Interval 7:15–7:20 and 7:20–7:25 have G4 to provide flex ramp, and the ramp constraints are not binding. In this case, the energy ramp constraint between 7:15–7:20 and 7:20–7:25 results in \$25 and \$35 prices for the two intervals respectively. These prices are consistent with the bids if the two intervals are considered together, but are not consistent with the bids on a single interval basis.

## Example 2 RTUC input

Gen	Online	En bid	FRP bid	En 6:47	Ramp rate	Pmin	Pmax
G1	6:00–10:00	25	0	400	100	0	400
G2	6:00–10:00	30	0	0	10	0	500
G3	6:00–10:00	36	10	0	60	0	500
G4	7:15–9:00	50	0	0	100	0	500

Changes from G1 highlighted in red.

Interval	Net system demand	Lower limit	Upper limit	FRU requirement	FRD requirement
7:00–7:15	500	n/a	n/a	510	0
7:15–7:30	799	700	1010	510	0

Flex ramp demand price \$20.

## Example 2 RTUC solution

	7:00–7:15		7:15–7:30	
Gen	En	FRU	En	FRU
G1	350	150	500	0
G2	150	150	299	150
G3	0	210	0	0
G4	0	0	0	500
Price	\$35	\$10	\$30	\$0

\$35 set by G1's energy bid and opportunity cost.

Opportunity cost = flex ramp price – flex ramp bid =  
 $10 - 0 = 10$ .

G1 is capacity limited. Having G1 to provide energy causes it to lose \$10 flex ramp profit, and the \$10 opportunity cost is added to its energy cost to compensate for the lost opportunity.

## Example 2 RTD1 input

Gen	Online	En bid	FRP bid	En 6:57	Ramp rate	Pmin	Pmax
G1	6:00–10:00	25	0	350	100	0	400
G2	6:00–10:00	30	0	50	10	0	500
G3	6:00–10:00	36	10	0	60	0	500
G4	7:15–9:00	50	0	0	100	0	500

Interval	Net system demand	Lower limit	Upper limit	FRU requirement	FRD requirement
7:00–7:05	400	n/a	n/a	170	0
7:05–7:10	500	450	570	240	0
7:10–7:15	600	550	740	310	0

Flex ramp demand price \$20.

## Example 2 RTD1 solution

	7:00–7:05		7:05–7:10		7:10–7:15	
Gen	En	FRU	En	FRU	En	FRU
G1	300	100	350	50	400	0
G2	100	50	150	50	200	50
G3	0	20	0	140	0	260
G4	0	0	0	0	0	0
Price	\$35	\$10	\$35	\$10	\$35	\$10

If the upper limit curve and lower limit are not changed in RTD2 and RTD3, RTD2 and RTD3 will produce the same solution for interval 7:05–7:10 and 7:10–7:15 as RTD1 optimization, so we omit RTD2 and RTD3 details.

The RTD flex ramp price is the same for all intervals. This is because the flex ramp price is set by a capacity not limited resource G3.

# Conclusion

- RTUC advisory headroom and flex ramp prices are generally different from RTD awards and prices
  - Due to difference in initial condition, resource availability, net system demand, and so on
- Flex ramp price
  - When there are more \$0 cost ramping capability in the system than the requirement, the flex ramp constraint is not binding, and has \$0 price
  - If the flex ramp price is set by capacity limited resource, it is likely that different RTD intervals over the study horizon have different flex ramp prices
  - If the flex ramp price is set by capacity not limited resource, it is likely that different RTD intervals over the study horizon have a uniform flex ramp price
- The flex ramp requirement may be updated every 5-minutes. If the change is small, the prices will be close to advisory solution from the previous RTD. This means that flex ramp does not introduce systematic price inconsistency over time.