Briefing on Pricing Enhancements

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Scope of this Initiative

1 Scope set forth in initial administrative pricing initiative
   - Administrative pricing rules,
   - Emergency tariff authority, and
   - Force Majeure.

2 Priority for schedules protected with existing transmission rights.

3 Compounded pricing of multiple contingencies.

4 Multiplicity of prices.

Item 1: Administrative Pricing Rules –Straw Proposal

- Use a three-tier approach for Administrative Pricing.
  - Tier I: use existing logic of last available price but only if prices are missing for less than 12 (RTD) or 4 (FMM) intervals.
  - Tier II: Use day-ahead prices if prices are missing for more than 11 (RTD) or 3 (FMM) intervals.
    - Allows for FMM and RTD substitution if one market is available.
    - Captures the time-based trend of prices.
    - Minimizes imbalance charges between markets.

Item 1: Administrative Pricing Rules –Straw Proposal

- Tier III:
  - To deal with market suspension only.
  - Use day-ahead (full LMP) prices.
  - No explicit region separation.
  - Imbalance charges will be washed out by using day-ahead prices for real-time.
  - Convergence bids will be liquidated at day-ahead prices. No winners or losers.
  - Congestion revenue rights are not impacted by market suspension of the real-time market.
  - IST trades will also settle at the day-ahead prices.

Item 1: Force Majeure, system emergency and settlement

- A need to distinguish force majeure events from system emergencies and/or market suspension.

- The administrative pricing proposal expressly addresses market disruption with or without market suspension.

- Tier III of administrative pricing is expected to be for very infrequent occurrences.

- Force majeure is not necessary linked to a system emergency or a market suspension.

Item 1: Furthermore, what if the day-ahead market is suspended?

- The ISO needs to plan for a catastrophic event that prevents the completion of the day-ahead market.
- If by 20hrs of the run day, the day-ahead results cannot be obtained, the day-ahead market will be suspended.
- In the absence of a day-ahead market solution,
  - Leave it fully up to the real-time market
    - With its limited time window, the real time market may not commit long start units.
    - This may require a lot more outside the market dispatches.
  - The ISO proposes to default to use the most recent and similar day results.

Item 3: Compounded pricing of multiple contingencies

- The Security Constraint Unit Commitment enforces transmission constraints for both base and contingency-related cases.

- All contingencies enforced are studied and defined through operations studies.

- With all the contingencies being credible, there is no mechanism to identify *a priori* the most severe contingency.

Item 3: Compounded pricing of multiple contingencies

Currently, each contingency is treated as an independent mathematical constraint, and if binding each one will usually have a shadow price.

$$\min \quad \sum_j c_i(x_i) + \sum_{k,c} \delta_k s_k^c$$

$$s.t. \quad \sum_i x_i = d$$

$$\sum_j a_{kj}^c x_j - s_k^c \le b_k^c, \quad \forall k,c$$

$$0 \le x_i \le \bar{x}_i, \quad \forall i$$

$$s_k^c \ge 0, \quad \forall k$$

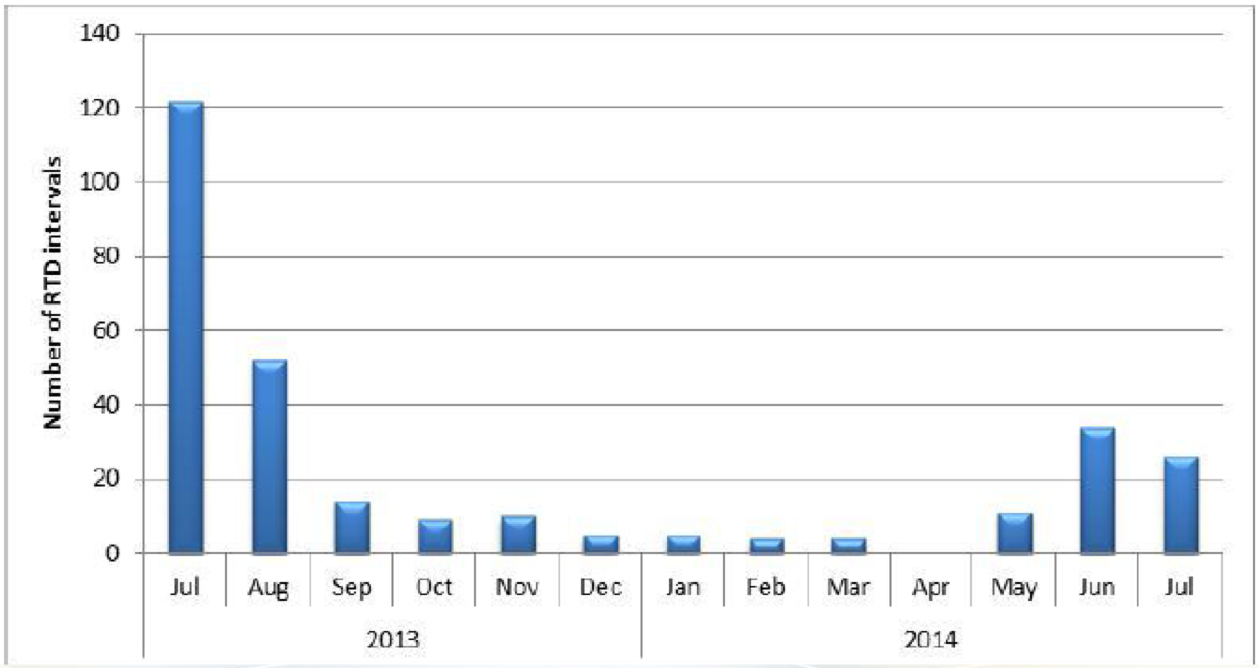
- Market solutions based on the administrative relaxation parameters indicate the system exhausted all controls to relieve congestion. Last resort is to use constraint relaxation.

Item 3: Compounded pricing of multiple contingencies

- If these constraints are binding based on the administrative relaxation parameters, compounded congestion may not provide any further economical relief.

- There have been instances where a constraint binds concurrently for multiple contingencies.

Figure 1: Frequency of RTD intervals experiencing concurrent binding of contingencies



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Item 3: Compounded pricing of multiple contingencies - Straw Proposal

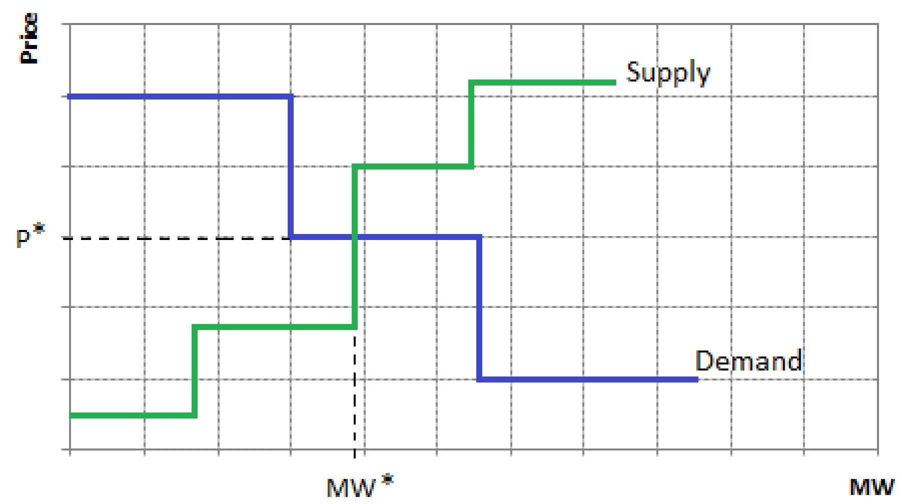
- The ISO is proposing to enhance the logic in the market to price only the most limiting contingency.
- All constraints, base and contingency cases, will be enforced as usual.

$$
\begin{aligned}
\min \quad & \sum_j c_i(x_i) + \sum_{k,c} \delta_k s_k^c \\
s.t. \quad & \sum_i x_i = d \\
& \sum_j a_{kj}^c x_j - s_k^c \le b_k^c, \quad \forall k,c \\
& 0 \le x_i \le \bar{x}_i, \quad \forall i \\
& s_k^s \ge 0, \quad \forall k
\end{aligned}
$$

$$
\begin{aligned}
\min \quad & \sum_j c_i(x_i) + \sum_{k} \delta_k s_k \\
s.t. \quad & \sum_i x_i = d \\
& \sum_j a_{kj}^c x_j - s_k \le b_k^c, \quad \forall k,c \\
& 0 \le x_i \le \bar{x}_i, \quad \forall i \\
& s_k^s \ge 0, \quad \forall k
\end{aligned}
$$

Item 4: Multiplicity of Prices

- The California ISO market uses a locational marginal pricing scheme, similar to other ISOs in the United States.
- The core of the optimization relies on a security constraint unit commitment (SCUC) and is solved with a mixed integer programming (MIP) methodology.
  - A common feature of electricity markets is the use of multi-segment bids, typically multi-step-wise bids.



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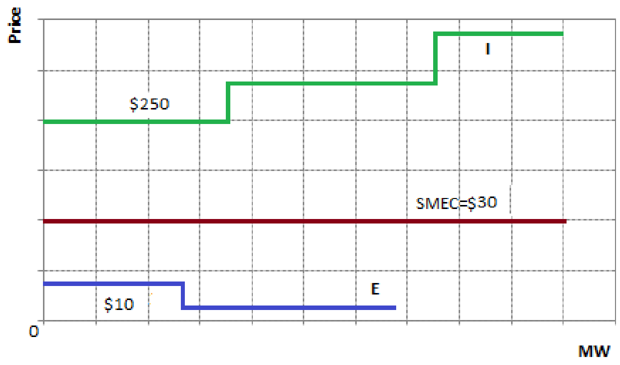
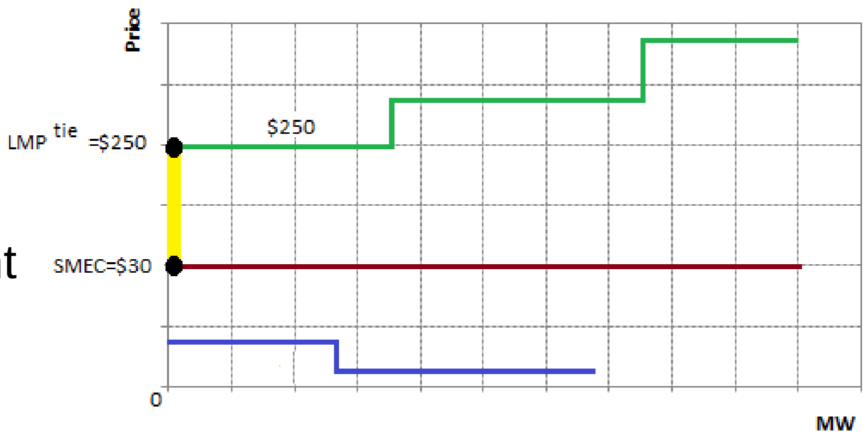
Item 4: Multiplicity of Prices

- Multiplicity of prices may arise in electricity markets and their root is deep in the mathematical formulation.
- Multiplicity of prices still reflects mathematically optimal solutions.
- The ISO has observed instances where multiplicity of prices arise under some scenarios, such as with intertie constraints.

Item 4: Multiplicity of Prices - Numerical example



- Bid stack for imports and export for an intertie with 0 MW limit in the export direction.
- At the solution, the system marginal energy cost is $30/MWh.
- 0 MW awards for imports and exports.



- The import bids set the price at the intertie location at $250
- Shadow price for the intertie constraint is at ($30-$250)=-$220 in the export direction

- Multiplicity of prices means
  - Shadow price for intertie =[0, -220] $/MWh, and
  - LMP at intertie scheduling point= [30, 250] $/MWh.

Item 4: Multiplicity of Prices –Straw Proposal

- Current formulation does not adopt specific rules to pre-determine a solution from the possible set.

- The ISO is proposing an enhancement to its formulation of pricing constraints.
- Consider for a reference the current formulation of the scheduling and pricing runs:

$$
\begin{aligned}
\min \quad & \sum_j c_i(x_i) + \sum_k \delta_k^s s_k^s \\
s.t. \quad & \sum_i x_i = d & & (\lambda) \\
& \sum_j a_{kj} x_j - s_k^s \le b_k, & \forall k \quad & (\mu_k) \\
& 0 \le x_i \le \bar{x}_i, & \forall i \quad & (\bar{\pi}_i) \\
& s_k^s \ge 0, & \forall k &
\end{aligned}
$$

$$
\begin{aligned}
\min \quad & \sum_j c_i(x_i) + \sum_k \left(\delta_k^p s_k^s + \delta_k^p s_k^p \right) \\
s.t. \quad & \sum_i x_i = d & & (\lambda) \\
& \sum_j a_{kj} x_j - s_k^s - s_k^p \le b_k, & \forall k \quad & (\mu_k) \\
& 0 \le x_i \le \bar{x}_i, & \forall i \quad & (\bar{\pi}_i) \\
& 0 \le s_k^s \le \hat{s}_k^s, & \forall k & \\
& 0 \le s_k^p \le \varepsilon^l, & \forall k &
\end{aligned}
$$

Item 4: Multiplicity of Prices –Straw Proposal

- The enhanced formulation modifies the current mathematical structure of the linear programming security constraint dispatch
  - The linear constraints are expanded with another slack
  - This slack variable is appended into the objective function.
  - The linear programming problem is now casted as a quadratic programming problem.
  - The formulation is convex, which guarantees uniqueness of prices.
  - The additional slack variable now competes with the existing slack variables to fulfill any constraint relaxation.
  - An epsilon associated with the new slack variable needs to be small enough to preserve the proper price signal.

Numerical example for constraint relaxation

- Solution in scheduling run:

G1=250 MW, LMP=$50

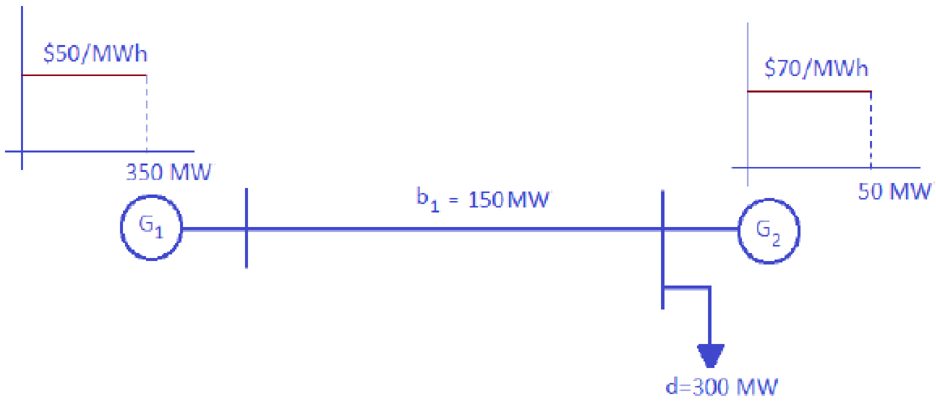
G2=50 MW, LMP=$5050

Line flow= 250 MW

Constraint relaxation=100MW

Shadow price for line constraint=-$5000

Shadow price for power balance=$5050



- Pricing run set-up

$$\min \quad 50G_1 + 70G_2 + 1000s_1^s + 1000s_1^p$$

$$s.t. \quad G_1 + G_2 = 300 \qquad (\lambda)$$

$$G_1 - s_1^s - s_1^p \le 150 \qquad (\mu_1)$$

$$0 \le G_1 \le 350$$

$$0 \le G_2 \le 50$$

$$0 \le s_1^s \le 100$$

$$0 \le s_1^p \le 0.1$$

Solution in pricing run:

G1=250 MW, LMP=$50

G2=50 MW, LMP=$1050

Line flow= 250 MW

Constraint relaxation=100MW

s_1^s = 100 MW, s_1^p=0 MW.

Shadow price for line constraint=-$1000

Shadow price for power balance=$1050

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Numerical example for constraint relaxation

- With the proposed formulation, the same expected solution reflecting relaxation is expected to be obtained.
- It is here where the epsilon parameter may play a role. In this example an Epsilon of 1E-3 is small enough to converge to the same solution

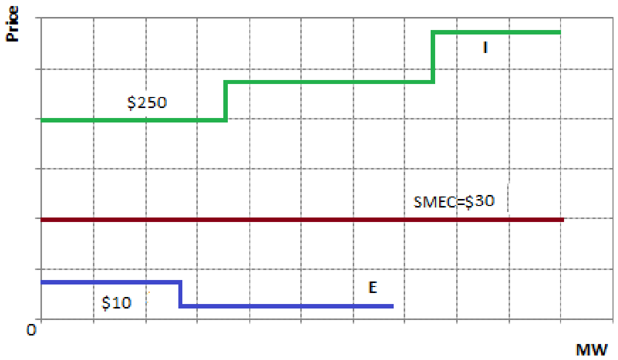
Table 2: Comparison of market solutions with different Epsilon values

ε^q	G_1	G_2	LMP_1	LMP_2	λ	μ_1
10	300	0	50	65	65	-15
1	250	50	50	150	150	-100
0.1	250	50	50	1050	1050	-1000
0.01	250	50	50	1050	1050	-1000
0.001	250	50	50	1050	1050	-1000

Further considerations

- The enhanced formulation will apply to both day-ahead and real-time markets.
- It will be applied to the pricing run since this is the run that produces the binding awards and prices.
- The formulation will apply programmatically to any transmission constraint that has an effect on locational marginal prices, including
  - power balance
  - flowgates, transmission corridors
  - scheduling limits
  - nomograms
  - EIM-related constraints

Item 4: Multiplicity of Prices -Numerical example with enhanced formulation



- Bid stack for imports and export for an intertie with 0 MW limit in the export direction.
- At the solution, the system marginal energy cost is $30/MWh.
- 0 MW awards for imports and exports.

- The LMP at the intertie scheduling point equals the SMEC=$30/MWh.

- Shadow price for the intertie constraint is $0/MWh.