Real-time Reserve Demand Curves (RDC)

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Background

- In the absence of direct demand bids in a one-sided market such as the capacity/reserve market, most ISOs/RTOs use administrative penalty prices for constraint violation
- A demand curve that represents the demand's willingness to pay for the corresponding product is economically more appealing
- ISOs/RTOs have implemented/proposed various designs of demand curves
  - ERCOT has implemented real-time Operating Reserve Demand Curves
  - ISO-NE has implemented local and system capacity demand curves
  - PJM recently proposed reserve demand curves (an *ex parte* matter that will not be discussed in this presentation)

In This Presentation

- We focus on the design of Real-time (RT) Reserve Demand Curves (RDCs)
- ISO-NE's RT reserve market will be used for the design, but the idea/approach can apply to different reserve market structures

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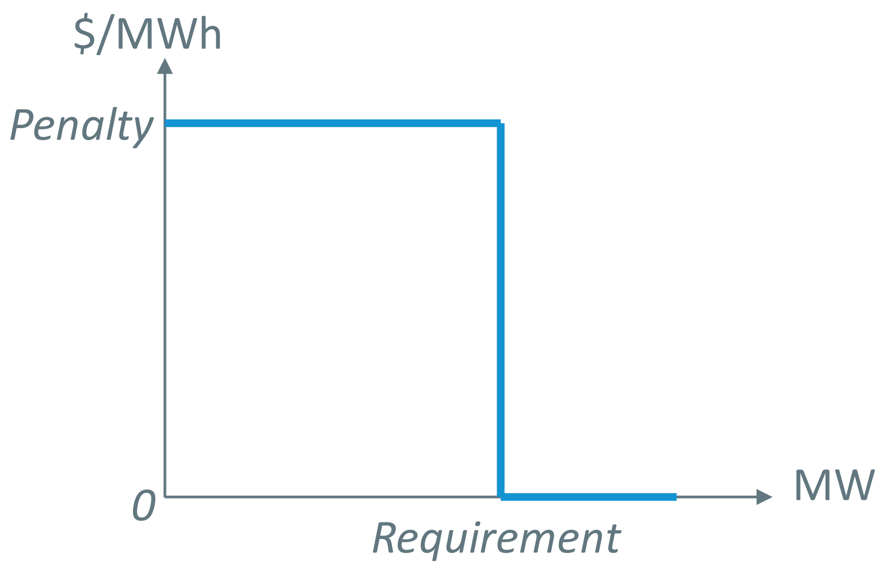
Issues with Reserve Penalty Price

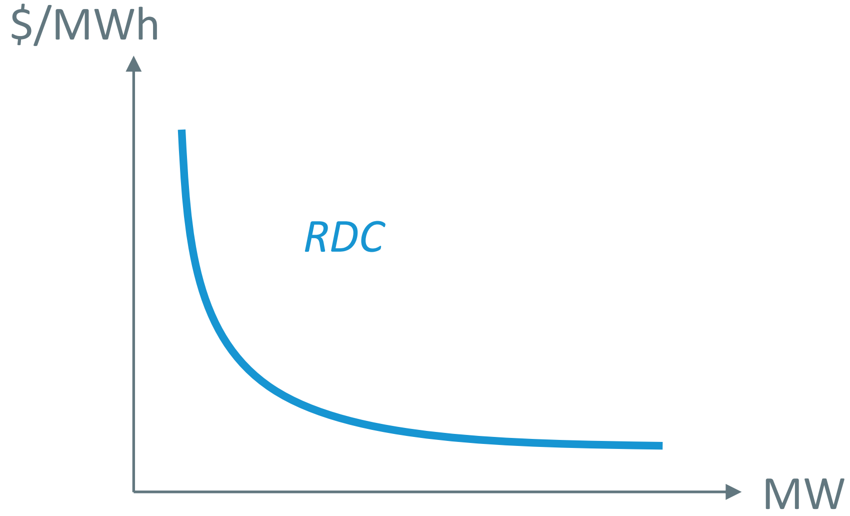
- The administratively-set reserve requirement (based on generator contingencies) with penalty price can be viewed as a step-wise RDC



- The curve does not reflect the diminishing economic value of increased reserve, and creates price volatility
- The single-value reserve requirement doesn't allow tradeoff between reliability and cost

Reserve Demand Curve

- A RDC reflects the demand's willingness to pay (measured in $/MWh) for reserve (reliability)
  – Monotonically decreasing as the marginal benefit of reserve (reliability) reduces with more reserve available



Challenges in RDC Design

- RDC should have an economic foundation
- RDC should relate to the existing reliability criteria
- In the presence of capacity market, the linkage between capacity and reserves needs to be reflected
- With multiple reserve products and local reserves, the corresponding RDCs need to be inherently consistent

Economic Foundation of RDC

- The economic benefit of reserve to the load can be measured by the negative Cost of Unserved Energy (CUE)
- Consider hourly cost (consistent with hourly energy cost):

  CUE = VOLL × LOL × 1h

  – Value of Lost Load (VOLL) is assumed constant across different loads
  – Loss of Load (LOL) is a function of reserve level *R*
- The **marginal benefit** of reserve defines RDC:

$$RDC(R) \equiv -VOLL \times \frac{dLOL(R)}{dR}$$

RDC in RT Dispatch

- A stylized energy and reserve co-optimization model with RDC:

$$Minimize_{\{p_i, r_i\}, R} \sum_i C_i(p_i) - \int_0^R RDC(R) \cdot dR$$

Pre-contingency dispatch cost

Reliability benefit of reserve

s.t.

$$\sum_i p_i = D, \quad (\lambda)$$

$$\sum_i r_i \geq R, \quad (\pi)$$

$$\sum_i SF_{l,i} \cdot (p_i - d_i) \leq f_{l\max}, \ \forall l, \quad (\mu_l)$$

$$p_{i\min} \leq p_i \leq p_{i\max}, \ \forall i$$

$$0 \leq r_i \leq r_{i\max}, \ \forall i$$

$$p_i + r_i \leq p_{i\max}, \ \forall i$$

Increased *R* (increased pre-contingency dispatch cost)

↓

Improved reliability (higher reliability benefit)

- RDC in a co-optimization allows tradeoff between dispatch cost and reliability benefit; Optimization picks the “right” (economic) level of reliability

Constructing RDC: Theory to Practice

- The theory does not address how to construct RDCs in practice
  - How to determine VOLL?
  - How to determine the RDC shape, i.e., dLOL(R)/dR?
- The economic framework does not address the links between various demand curves
  - Local and system RDCs
  - RDCs for multiple reserve products: 10-min spin/non-spin, 30-min reserve
  - Capacity demand curve

General Issues with Existing Approaches

- VOLL is set at an administrative value that is subject to debate
- The curve shape based on normal distribution lacks justification
- No clear connection among demand curves for capacity and various reserve types
- In general, existing approaches use many assumptions that lack a rigorous foundation, and therefore are difficult to extend and defend

A generic and systematic approach for constructing RDCs, that is also consistent with the theoretical foundation, is desired

Proposed Method for Constructing RDC: LOL

- From the theoretical framework:

$$RDC(R) = -VOLL \times \frac{dLOL(R)}{dR}$$

- The key is to estimate LOL(R) and VOLL
- LOL depends on system state including but not limited to the reserve level *R*, therefore is multi-variate in nature
- LOL(R) as a single-variable function of *R,* averages on all other state variables
- It's impractical to simulate all possible system states with the huge-size state space and lack of state probability distribution

Method for Constructing RDC: LOL – Cont'd

- Our approach for LOL(R) is to use historical RT dispatch cases
  - Historical cases reflect possible system states statistically
- For each dispatch case,
  - the system state including the available reserve level R is known
  - LOL is evaluated by simulating generator outages
  - a pair (R, LOL) is obtained

Proposed Method for Constructing RDC: VOLL

- Unlike other methods, VOLL is implied from market equilibrium
- Assume that in short-run market equilibrium, a Marginal Unit's Operating Cost (MUOC) equals the marginal cost of unserved energy; and the equilibrium is reached at the desired reliability level represented by the reserve requirement R_0, then

$$MUOC = -VOLL \times \left. \frac{dLOL(R)}{dR} \right|_{R=R_0}$$

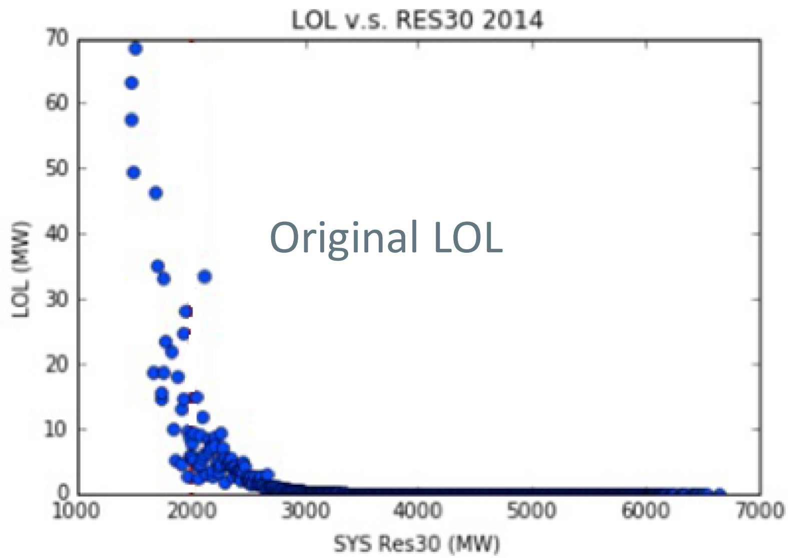
- Therefore, VOLL for reserve is calculated as

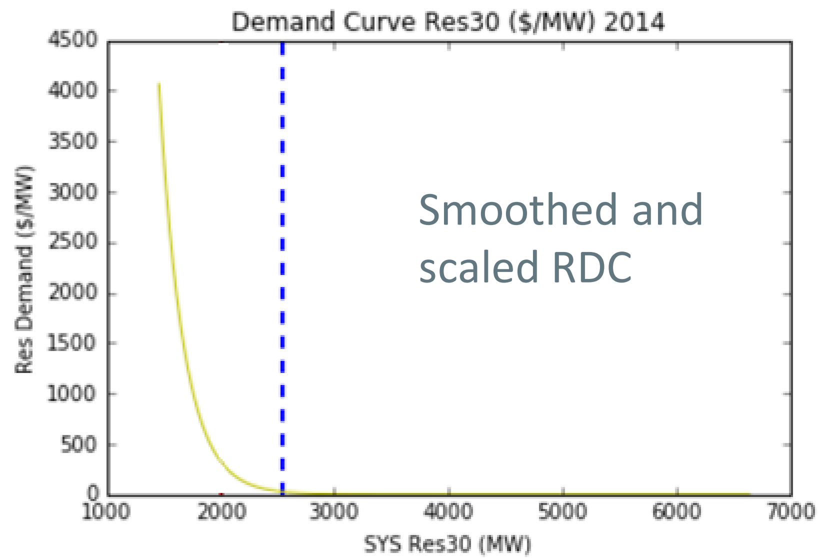
$$VOLL = -\frac{MUOC}{\left. \frac{dLOL(R)}{dR} \right|_{R=R_0}}$$

Connection Between Reserve and Capacity

- Capacity market is intended to recover the missing money, i.e., Net Cost of New Entry (CONE), or CONE less the expected revenue from energy and reserve markets
- VOLL serves as a scalar factor for both capacity and reserve demand curves: If reserve VOLL increases, the Net CONE decreases and the capacity VOLL decreases; and vise versa
- There are multiple choices of scalar factors for capacity and reserve demand curves to ensure the total revenue recovers the total cost for the "marginal" resource
  - This allows revenue transfer between capacity and reserve markets

Preliminary Results for 30min RDC

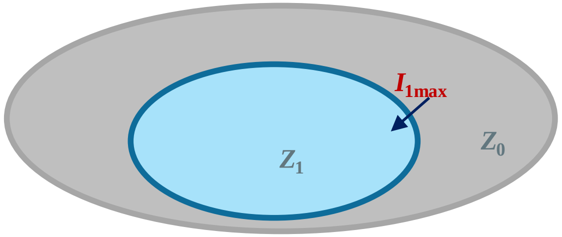




- The test is based on Year 2014's 5-min dispatch cases
- Average 30min reserve requirement R_0 is about 2540 MW
- MUOC is $40.93/MWh based on the parameters of capacity new entry in for the year
- VOLL is calculated as $34,155/MWh
- Exponential curve fitting is used to generate the smooth RDC

Local Reserve Zones

- Reserve zones in ISO-NE are associated with import interface constraints



- The reserve in the import-constrained zone has more reliability value than the reserve outside
- The zonal RDC should capture the "*additional*" marginal reliability benefit

Zonal RDC

- The zonal RDC is defined as a function of the zonal reserve R_1

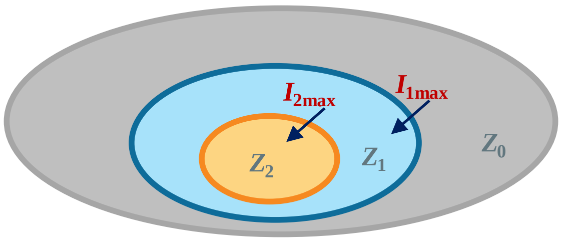
$$RDC_{Z_1}\left(R_1\right) = -VOLL \times \frac{d\left[LOL_{I1}\left(R_1\right) - LOL_{\phi}\left(R_1\right)\right]}{dR_1}$$

  - LOL_{I1} is the evaluated with the presence of import interface constraint
  - LOL_{ϕ} is the evaluated without the import constraint
- $LOL_{I1} \geq LOL_{\phi}$: the difference reflects the additional reliability benefit of zonal reserve over outside reserve
- The marginal additional benefit decreases as the zonal reserve R_1 increases, and diminishes to zero as R_1 is large enough

Multiple Reserve Zones

- For multiple reserve zones at the same level, zonal RDCs can be calculated independently
- The underlying assumption is that the import constraints associated with the two zones do not impact each other
  - Probability of LOL in both zones is low
  - The zones are geographically apart

Nested Reserve Zones



- The RDC for Zone 1 is calculated the same way as before
- The RDC for Zone 2 is calculated based on the LOL difference with and without the I_2 interface limit

$$RDC_{Z_2}(R_2) = -VOLL \times \frac{d\left[LOL_{I_2,I_1}(R_2) - LOL_{I_1}(R_2)\right]}{dR_2}$$

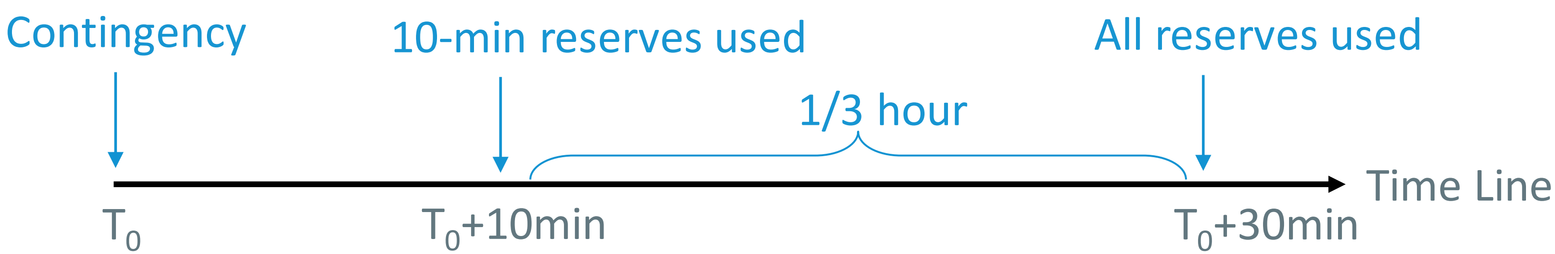
  - $LOL_{I2,I1}$ is the evaluated with the presence of both interfaces
  - LOL_{I1} is the evaluated with the interface constraint 1 only

Multiple Reserve Products

- Consider three RT reserve products: 10-min spinning, 10-min non-spinning and 30-min reserves
- RDCs of multiple reserve products should preserve the hierarchical relations among reserves of different qualities
  - The reliability benefit of one unit of higher-quality reserve shall be more than that of lower-quality reserve
  - The “additional” reliability of high-quality reserve defines its RDC
- 30-min RDC calculated first serves as a base

RDC for 10-min Reserve

- The 10-min reserve can be converted to energy in 10 minutes while the 30-min reserve takes 30 minutes



  - LOL_0 is the LOL at time T_0 with no reserves used
  - LOL_{10} is the LOL at T_0+10min with 10-min reserves used
- The additional benefit of 10-min reserve over 30-min reserve is $\Delta LOL^{10} = (LOL_{10} - LOL_0)$, lasting 1/3 hour

$$RDC^{10}\left(R^{10}\right) = -VOLL \times \frac{1}{3} \times \frac{d\left(\Delta LOL^{10}\right)}{dR^{10}}$$

RDC for 10-min Spinning Reserve

- A 10-min fast-start unit when online tends to be more responsive than when it's offline
  - Online outage rate < Offline "outage" rate
  - LOL with online rates < LOL with offline rates
- The additional benefit of 10-min spinning reserve over non-spinning reserve is
  - $\Delta LOL^{10S} = LOL_{10}$(online rate) – LOL_{10}(offline rate), lasting 1/3 hour
- The RDC for 10-min spinning reserve is

$$RDC^{10S}\left(R^{10S}\right) = -VOLL \times \frac{1}{3} \times \frac{d\left(\Delta LOL^{10S}\right)}{dR^{10S}}$$

More Implementation Details to Explore

- RDC models based on time of the day and seasons?
- How often RDC curves should be updated?
- How many historical cases are needed to calculate a RDC?
- How to estimate the MUOC?

Conclusion

- A comprehensive methodology is established to derive consistent RDCs for system, local and multiple reserve products
- VOLL as a scaling factor for RDC is implied from market equilibrium and marginal unit costs
- With the methodology applying to capacity market, RDC relates to capacity demand curve through VOLL, providing design flexibility between capacity and reserve markets
- Our systematic approach allows a more effective debate on the RDC methodology itself than on the curve details - once the methodology is agreed upon, the curve design will follow