Demand Curves in Forward Capacity Market (FCM)

Feng Zhao, Tongxin Zheng, Eugene Litvinov

ISO NEW ENGLAND

Forward Capacity Market in ISO-NE

- ISO-NE runs a 3-year ahead Forward Capacity Market (FCM) to ensure system and local resource adequacy
- ISO-NE's FCM can model Import Constrained Zones (ICZ), Export Constrained Zones (ECZ), and the Rest of System (ROS)
- The ISO establishes **System and Zonal capacity requirements** prior to the capacity auction
- Capacity resources submit offers in the corresponding zones, and the ISO clears FCM in a least-cost fashion to meet the system and zonal requirements

Capacity Requirements in FCM

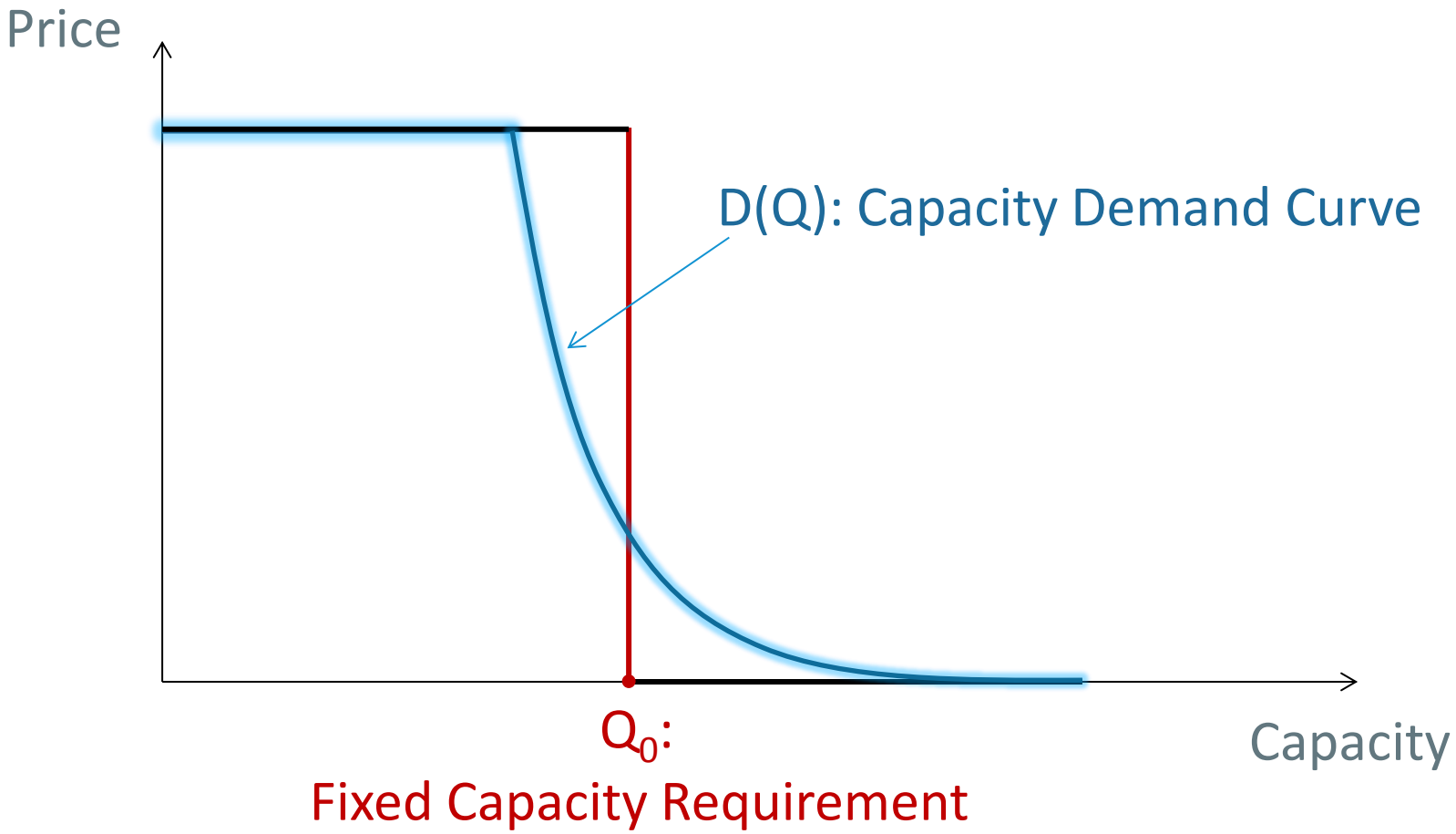
- System and zonal capacity requirements are surrogates for system reliability
- The ISO determines the capacity requirements through resource adequacy studies to maintain the Loss of Load Expectation (LOLE) of 0.1 days/year
  - The system-wide requirement is “Installed Capacity Requirement” (ICR)
  - The requirement for an Import Zone is “Local Source Requirement” (LSR)
  - The limit for an Export Zone is “Maximum Capacity Limit” (MCL)

Issues with Fixed Capacity Requirements

- Fixed capacity requirement, or vertical capacity demand curves, may lead to volatile capacity prices, increasing risk for investment and load
- No economic tradeoff between different reliability levels
- No economic tradeoff between different zones

Solution: **Sloped Capacity Demand Curves**

Capacity Demand Curve Illustration



Major Challenge For Capacity Demand Curves

- Capacity demand curves should reflect consumers' willingness to pay for capacity, or "reliability"
- However, reliability is treated as a public good and there are *no* private capacity demand bids in FCM
- The **major challenge** for designing capacity demand curves is to reflect their economic essence, i.e., the value of reliability, without direct expression from the consumers

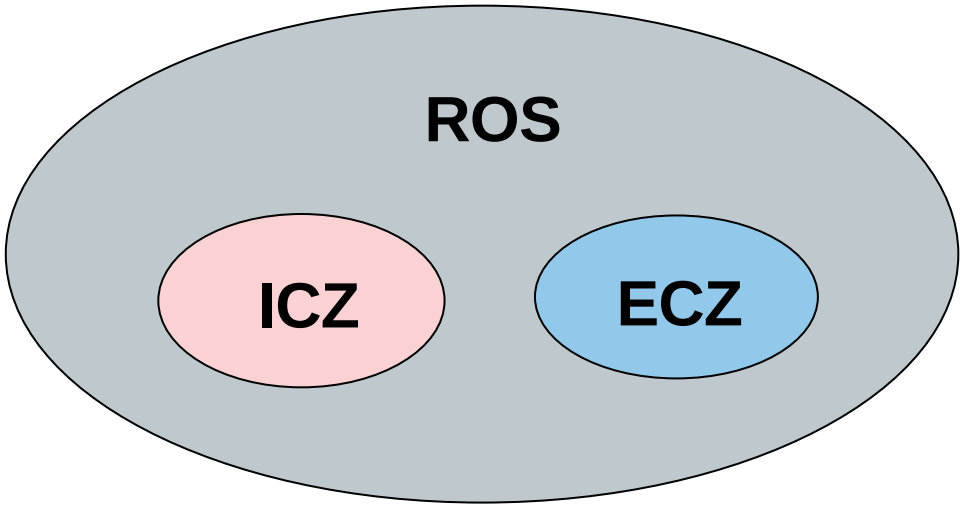
Technical Challenge For Capacity Demand Curves

- As a public good, reliability is defined at the system level and measured by the system-level indices
- However, system reliability is affected by not only the total system capacity, but its allocation among the zones as well
- Therefore, reliability is a multi-variate function of the capacities in different zones
- The **technical challenge** is to decompose the multi-variate reliability function into individual single-variable functions that appropriately reflect the reliability impact of different zones

Outline

- **Overview** of ISO-NE's Forward Capacity Market (FCM)
- **Issues** with fixed capacity requirements
- **Challenges** for designing capacity demand curves
- An **illustrative FCM problem**
- **Value of Reliability** and its decomposition
- **Capacity Demand Curves**
- **Conclusion**

An Illustrative FCM Problem



The system is composed of an Import-Constrained Zone (**ICZ**), an Export-Constrained Zone (**ECZ**), and the Rest of System (**ROS**) zone

FCM Model with Capacity Demand Curves

$$Minimize_{\{q_r, Q_{SYS}, Q_{ICZ}, Q_{ECZ}\}} \sum_{r \in Z_{ICZ} \cup Z_{ECZ} \cup Z_{ROS}} C_r(q_r)$$ Cost of Capacity

$$-\left\{\int_0^{Q_{SYS}} D_{SYS}(Q) \cdot dQ + \int_0^{Q_{ICZ}} D_{ICZ}(Q) \cdot dQ + \int_0^{Q_{ECZ}} D_{ECZ}(Q) \cdot dQ\right\}$$

$$s.t. \quad \sum_{i \in Z_{ICZ}} q_i + \sum_{j \in Z_{ECZ}} q_j + \sum_{k \in Z_{ROS}} q_k \geq Q_{SYS}$$ ~~ICR~~ System Capacity Requirement

$$\sum_{i \in Z_{ICZ}} q_i \geq Q_{ICZ}$$ ~~LSR~~ Local Source Requirement for the import zone

$$\sum_{j \in Z_{ECZ}} q_j \leq Q_{ECZ}$$ ~~MCL~~ Maximum Capacity Limit for the export zone

$$q_r \in \Omega_r,\ r \in Z_{ICZ} \cup Z_{ECZ} \cup Z_{ROS}$$

$D_{SYS}(\cdot)$, $D_{ICZ}(\cdot)$ and $D_{ECZ}(\cdot)$ are system and zonal **capacity demand curves** replacing the fixed requirements/limits – **How to derive them?**

Capacity Demand Curve Design Guidelines

- Based on rigorous **economic foundation and reliability theory**
- Allow **tradeoffs** between different reliability levels and zones
- Clear and **justifiable** assumptions and approximations
- Viable for **practical** implementation

Reliability Measure

- Reliability can be measured by indices such as Lost of Load Expectation (LoLE), which has been used in **calculating fixed requirements** to maintain system-wide **LoLE ≤ 0.1 days/year**
- LoLE captures the '*frequency*' of loss of load, but does not reflect the '*severity*" of loss of load
- **Expected Unserved Energy** (EUE) captures both frequency and severity of loss of load, and therefore is used to calculate the value of reliability

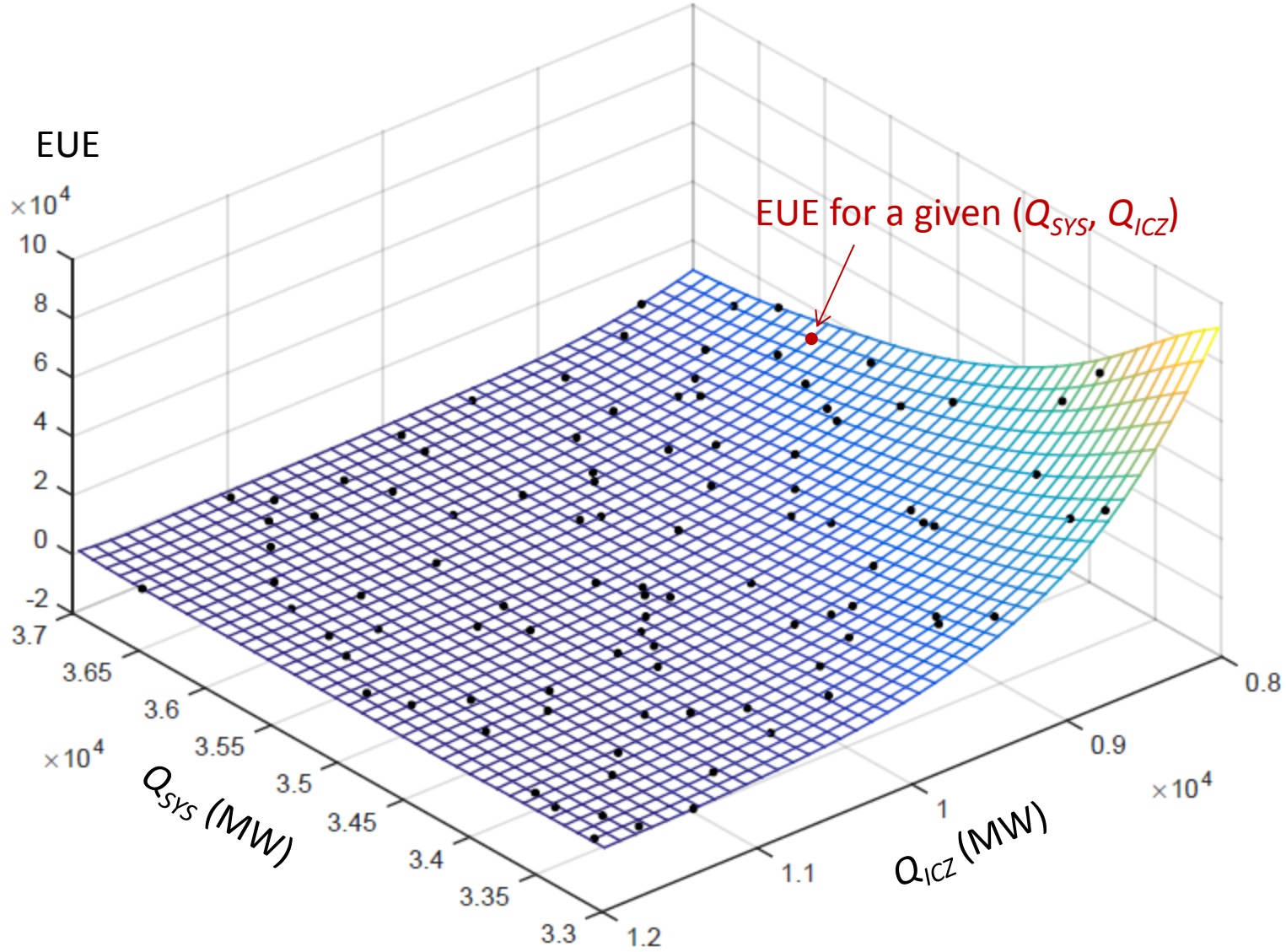
Expected Unserved Energy

- Unserved energy could be caused by deficiency in system capacity or limitation of the transfer capability between zones
- Therefore, system reliability is impacted by both the total system capacity and its allocation among zones
- Denote the capacities in system, ICZ and ECZ respectively, by Q_{SYS}, Q_{ICZ} and Q_{ECZ}; then the system reliability, measured by EUE, is a **multivariate function** of the three capacity variables:

$$EUE\left(Q_{SYS}, Q_{ICZ}, Q_{ECZ}\right)$$

Decomposition is needed to obtain single-variable demand functions

Illustrative Multivariate EUE Function: 2-Zone



EUE Decomposition

- Unserved energy can be caused by **system capacity deficiency** or the **allocation of capacity** (in the presence of interface limits)
- Therefore, $EUE(Q_{SYS}, Q_{ICZ}, Q_{ECZ})$ can be decomposed as

$$EUE\left(Q_{SYS}, Q_{ICZ}, Q_{ECZ}\right) = EUE_{SYS}\left(Q_{SYS}\right) + EUE_{A|SYS}\left(Q_{ICZ}, Q_{ECZ} \mid Q_{SYS}\right)$$

unserved energy caused by system capacity deficiency

Additional unserved energy caused by the allocation of system capacity to zones given the system capacity

EUE Decomposition Ctn'd

- The additional reliability impacts of zones are considered **independent** of each other, as in the existing calculation of zonal capacity requirements
- Then EUE is further decomposed into zones

$$EUE_{A|SYS}\left(Q_{ICZ}, Q_{ECZ} \mid Q_{SYS}\right) \approx EUE_{ICZ|SYS}\left(Q_{ICZ} \mid Q_{SYS}\right) + EUE_{ECZ|SYS}\left(Q_{ECZ} \mid Q_{SYS}\right)$$

EUE caused by allocating Q_{ICZ} out of the total system capacity to the *ICZ*

EUE caused by allocating Q_{ECZ} out of the total system capacity to the *ECZ*

EUE Decomposition Ctn'd

- The additional reliability impact of a zone does **not vary significantly** with respect to the total system capacity as verified with the NE system
- Then the total system capacity in the additional reliability impact function can be **fixed at** the nominal value of **ICR** that corresponds to the 1-day in 10-year *LoLE*

$$EUE_{ICZ|SYS}\left(Q_{ICZ} \mid Q_{sys}\right) \approx EUE_{ICZ|SYS}\left(Q_{ICZ} \mid ICR\right)$$

$$EUE_{ECZ|SYS}\left(Q_{ECZ} \mid Q_{sys}\right) \approx EUE_{ECZ|SYS}\left(Q_{ECZ} \mid ICR\right)$$

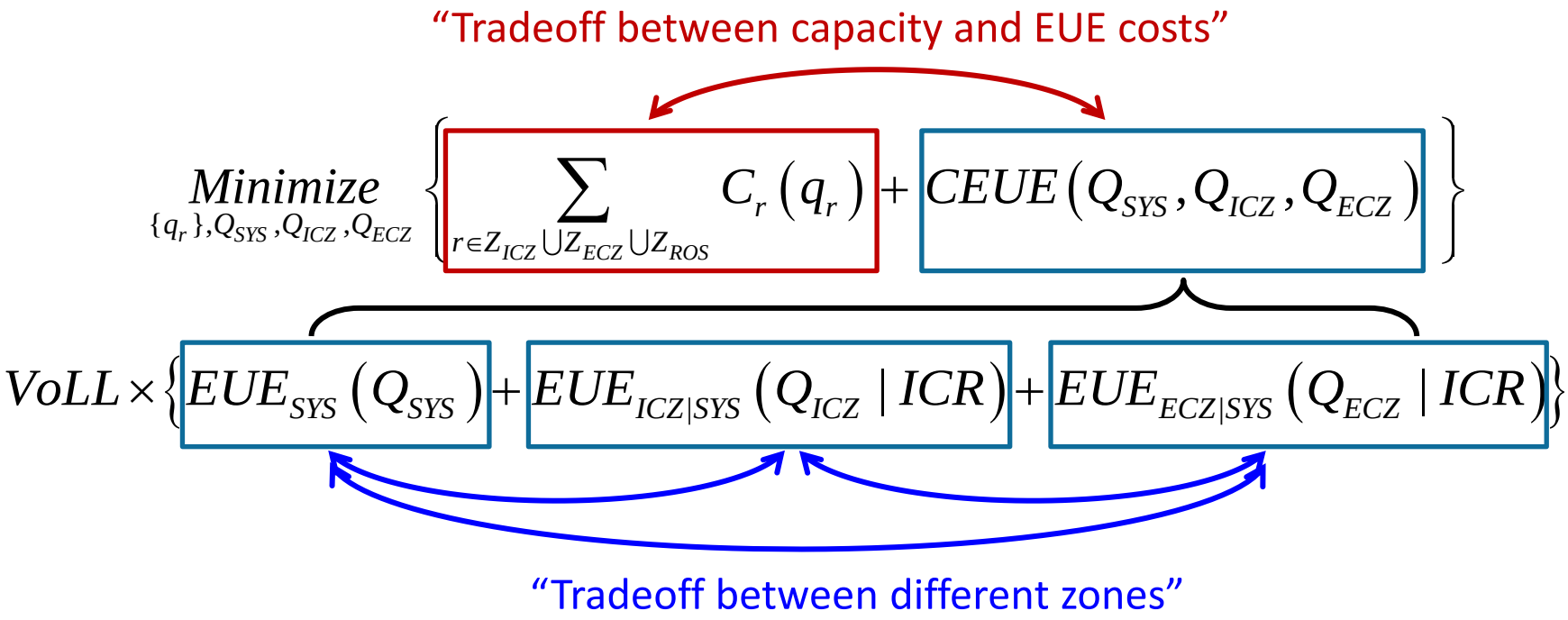
The Value of Reliability

- To measure the value of reliability, we introduce the **Value of Lost Load** (*VoLL*) parameter in $/MWh
- Reliability is treated as a public good, so *VoLL* is considered the same for all zones
- With *VoLL* and *EUE*, the **Value of Reliability** is measured by the **Cost of Expected Unserved Energy** (CEUE):

$$CEUE\left(Q_{SYS}, Q_{ICZ}, Q_{ECZ}\right) \equiv VoLL \times EUE\left(Q_{SYS}, Q_{ICZ}, Q_{ECZ}\right)$$
$$= VoLL \times \left\{EUE_{SYS}\left(Q_{SYS}\right) + EUE_{ICZ|SYS}\left(Q_{ICZ} \mid ICR\right) + EUE_{ECZ|SYS}\left(Q_{ECZ} \mid ICR\right)\right\}$$

Social Surplus Maximization

- According to microeconomic theory, the objective of FCM is to maximize the total social surplus
- Or equivalently, the objective is to minimize the **cost of capacity** to generators **and** the **cost of unserved energy** to loads, i.e.,



Capacity Demand Curves

- Comparing the **social cost minimization** objective with the objective of the **FCM model** with capacity demand curves, we obtain the following demand curves:

$$D_{SYS}\left(Q_{SYS}\right) = -VoLL \times \frac{dEUE_{SYS}\left(Q_{SYS}\right)}{dQ_{SYS}}$$ *"$ per MW-Year"*

$$D_{ICZ}\left(Q_{ICZ}\right) = -VoLL \times \frac{dEUE_{ICZ|SYS}\left(Q_{ICZ} \mid ICR\right)}{dQ_{ICZ}}$$

$$D_{ECZ}\left(Q_{ECZ}\right) = -VoLL \times \frac{dEUE_{ECZ|SYS}\left(Q_{ECZ} \mid ICR\right)}{dQ_{ECZ}}$$

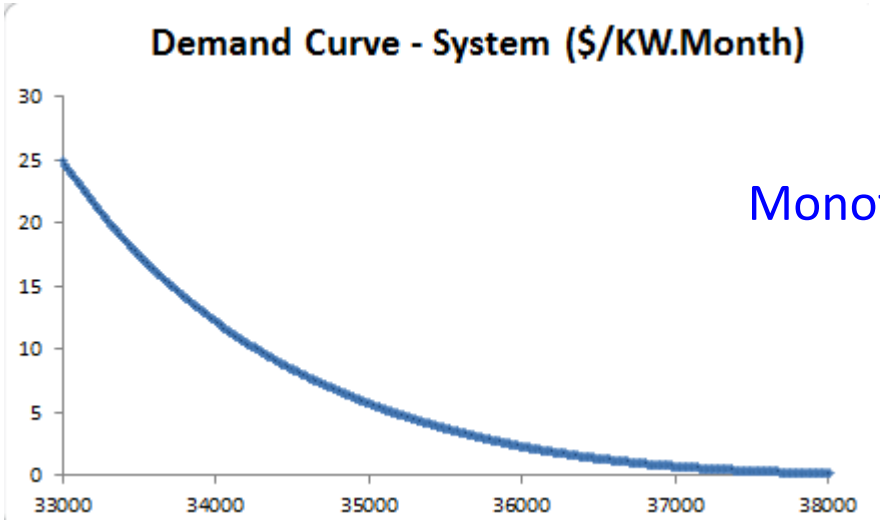
Meanings of Capacity Demand Curves

- $D_{SYS}(Q_{SYS})$ represents the marginal reliability cost of system capacity without considering zones
- $D_{ICZ}(Q_{ICZ})$ represents the marginal reliability cost of shifting capacity from the rest of system into ICZ
- $D_{ECZ}(Q_{ECZ})$ represents the marginal reliability cost of shifting capacity from the rest of system into ECZ

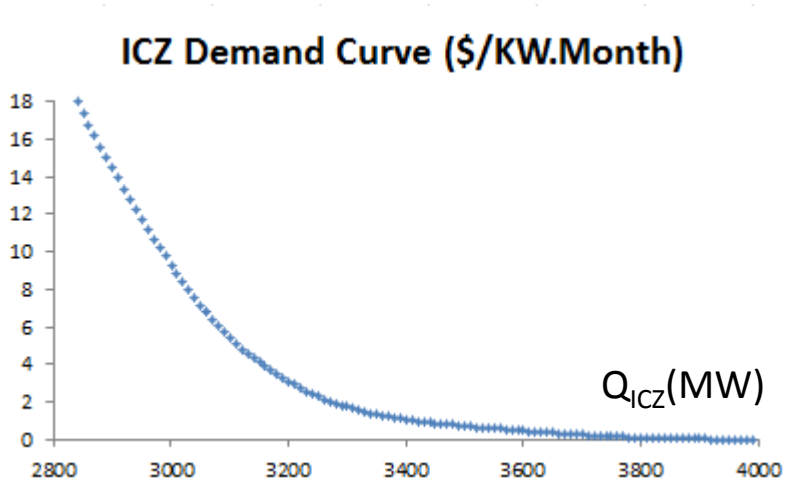
Calculation of *VoLL*

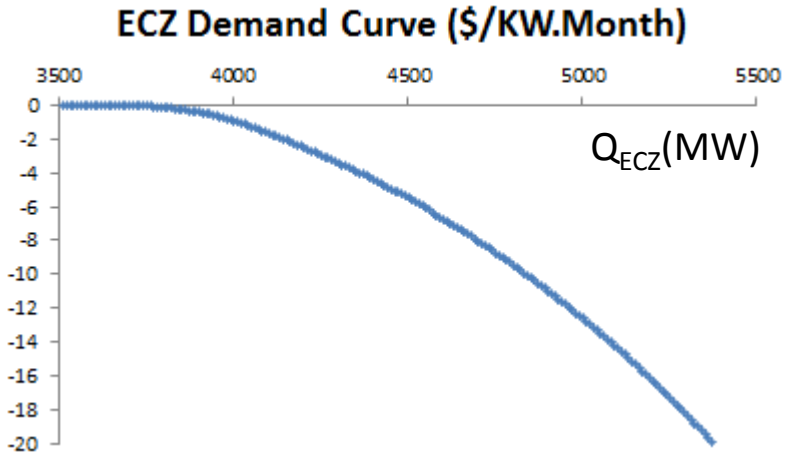
- Under the **long-term market equilibrium**, the **marginal value of reliability** at the desired reliability level (i.e., 1-day in 10-year LoLE) should be *equal* to the **marginal cost of new entry** for each zone
- The marginal cost of new entry, i.e., *Net Cost of New Entry* (**Net CONE**), is determined by the ISO under reasonable assumptions prior to the FCM
- *VoLL* is implied from the *Net CONE* values based on the long-term market equilibrium property

Illustrative Capacity Demand Curves



Monotonically Decreasing!





Conclusion

- We propose a **sensible economic framework** for designing capacity demand curves in FCM
- The resulting demand curves **allow cost trade-offs** between different capacity zones and different reliability levels
- Necessary and justifiable **decompositions** are used to obtain zonal demand curves
- The design retains existing reliability evaluations as core elements, and therefore is **viable** for practical implementation
- The proposed framework provides possibilities for exploring interesting questions (VoLL estimation, NET CONE values, appropriate reliability level, etc.)