Risk-limiting Economic Dispatch:

Electricity Markets with Flexible Ramping Products

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What is Flexible Ramping?

- **Definition:**

  Conceptually, the flexible ramping product [CAISO, MISO] aims to provide more ramping capacity (flexibility) to the system by reserving capacity in the current time slot for future use.
- **Differences compared with existing products:**
- **Ramping flexibility:**

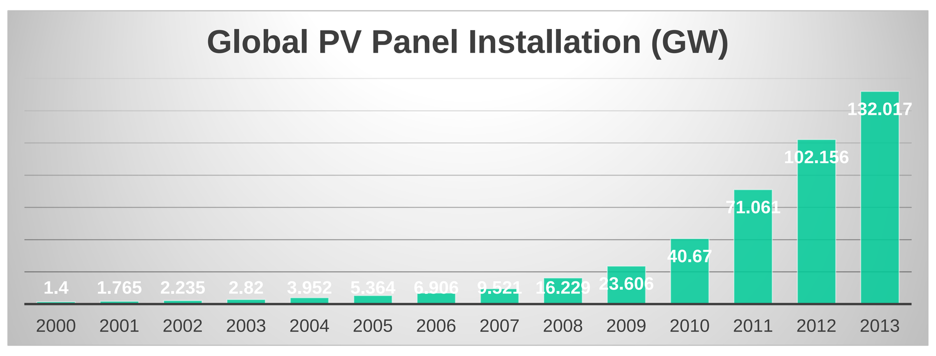
  Spinning reserve;

  non-spinning reserve
- **Time Scale:**

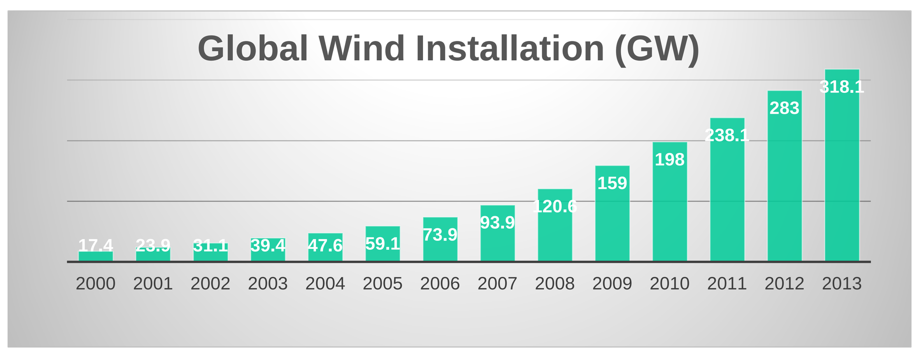
  Frequency Regulation

Motivation

- **Renewable energy is here:**



(Data: IEA-PVPS. 2014. PVPS Report Snapshot of Global PV 1992-2013)

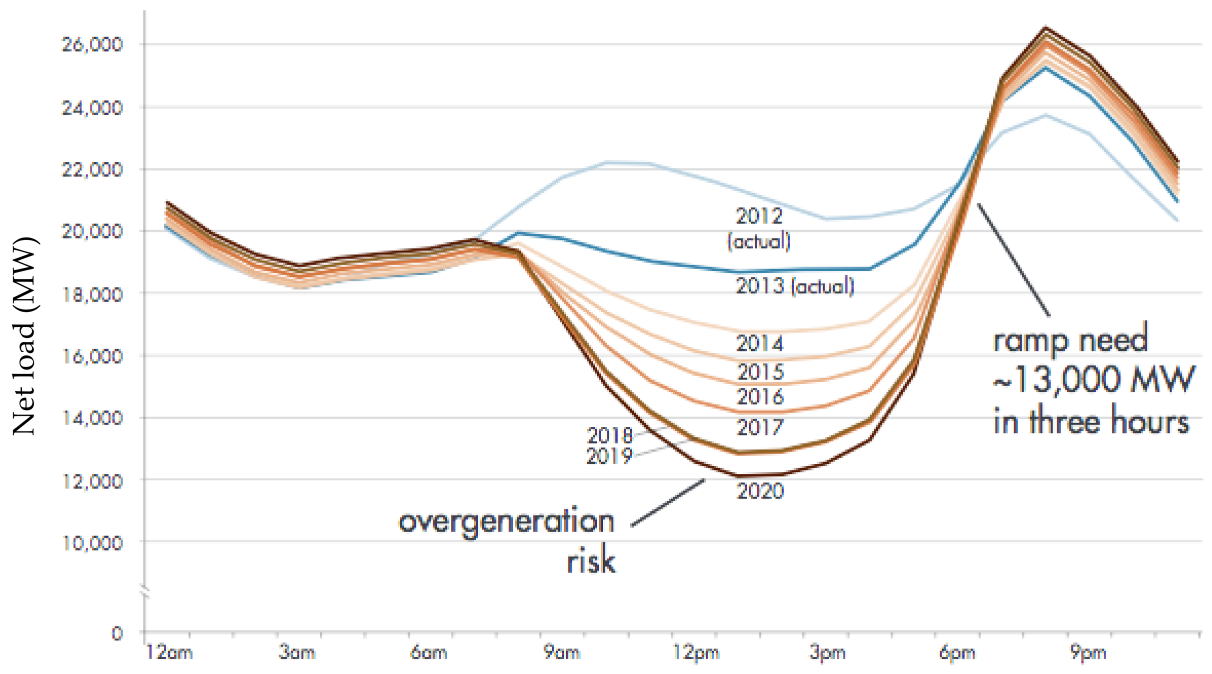


(Data: GWEC)

It injects huge ramps in minute scale.

E.g., the output of one huge wind farm could change several GW in several minutes.

- **Steep ramp across the day:**



Net load curves for March 31, from 2012 to 2020, based on analysis by California ISO. Source: Inside Energy, Data: California ISO.

- **Consider the following scenario: during the steep ramp, what if there is a sudden drop in the output of wind farm? What will happen if there is no other reserved ramping up capacities?**

The combination of both factors warrant incorporating flexible ramping products into the electricity markets.

In addition, the recent task force to evaluate power system flexibility by NERC demands new products for the future electricity market to enhance the total ramping capacity which will enable coping with any potential steep deviation from renewable predictions.

How to Utilize the New Products?

- **Risk (variation of LOLP)**:

  $$\Pr\{-f^d \le \underbrace{d^t - \hat{d}^t}_{\text{prediction error}} \le f^u\} \ge p, \forall t.$$

- **Key parameters**

  up flexible ramp requirement f^u

  down flexible ramp requirement f^d

- **How to determine these key parameters?**

  Risk-limiting Economic Dispatch

Risk-limiting Economic Dispatch

$$\min_{q, f^d, f^u} \sum_{t=1}^{T} \sum_{s \in S_q} cost_s(q_s^t)$$

$$s.t.\ \Pr\{-f^d \le d^t - \hat{d}^t \le f^u\} \ge p, \forall t$$

$$\left.\begin{aligned} \textstyle\sum_{s\in S_q} r_s^{u,t} \ge f^u \\ \textstyle\sum_{s\in S_q} r_s^{d,t} \ge f^d \end{aligned}\right| \text{flexible ramping requirements}$$

line capacity constraints on q_s^t

ramping capacity constraints on $q_s^t, r_s^{u,t}, r_s^{d,t}$

generation capacity constraints on $q_s^t, r_s^{u,t}, r_s^{d,t}$

Why Brute-force not Efficient?

Step 1: Enumerate a feasible (f^d, f^u) satisfying

$$\Pr\{-f^d \le d^t - \hat{d}^t \le f^u\} \ge p, \forall t.$$

Step 2: Compute the generation cost for (f^d, f^u)

$$\min_{q, f^d, f^u} \sum_{t=1}^{T} \sum_{s \in S_q} cost_s(q_s^t)$$

$$s.t.\ \sum_{s\in S_q} r_s^{u,t} \ge f^u$$

$$\sum_{s\in S_q} r_s^{d,t} \ge f^d$$

line capacity constraints

ramping capacity constraints

generation capacity constraints

Step 3: Check if the generation cost is the current minimal.

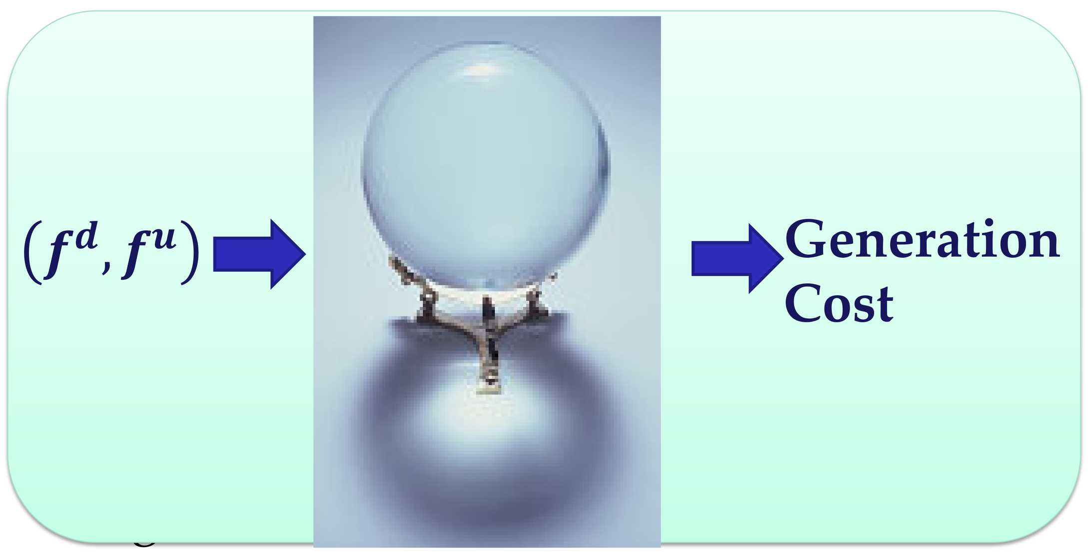
Key Challenge: Step 2 is not efficient!

What if We Have an Oracle?

Step 1: Enumerate a feasible (f^d, f^u) satisfying

$$\Pr\{-f^d \le d^t - \hat{d}^t \le f^u\} \ge p, \forall t.$$

Step 2: Compute the generation cost for (f^d, f^u)



Step 3: Check if the generation cost is the current minimal.

Now, the brute-force search is just a linear search!

How to Construct the Oracle?

Parametric Analysis:

$$\mathrm{MinC}(f^d, f^u) = \min_{q} \sum_{t=1}^{T} \sum_{s \in S_q} cost_s(q_s^t)$$

$$s.t.\ \sum_{s\in S_q} r_s^{u,t} \ge f^u$$

$$\sum_{s\in S_q} r_s^{d,t} \ge f^d$$

line capacity constraints

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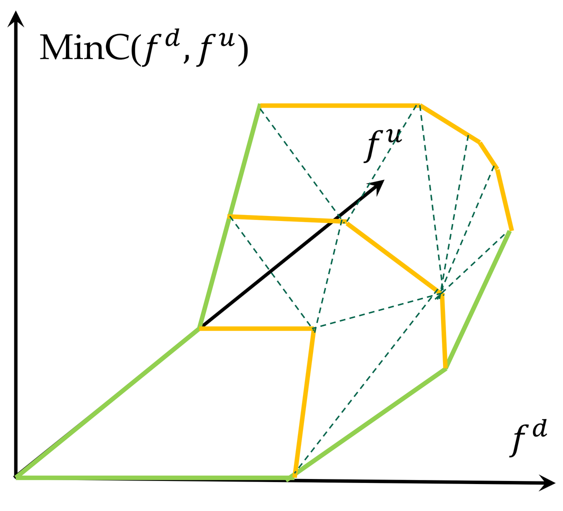
Observations: monotone, convex, piecewise linear, triple optimality.

Benefits: utilizing Lagrangian, the function can be constructed efficiently.



Given (f_q^d, f_q^u), what is $\mathrm{MinC}(f_q^d, f_q^u)$?

Search which triangle (f_q^d, f_q^u) belongs to.

Obtain $\mathrm{MinC}(f_q^d, f_q^u)$ by the weighted sum of the three end points of the triangle.

Theorem:

There won't be too many triangles! The number of triangles is almost linear in the number of variables and inequality constraints.

Thus, we construct the oracle to enable efficient query.

Simulation Results: WECC 240-Bus System

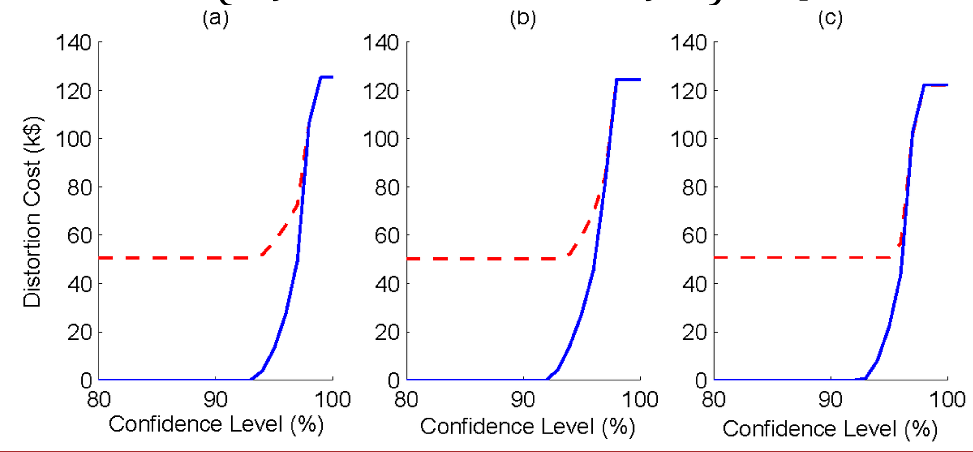
Performance Evaluation: DS function

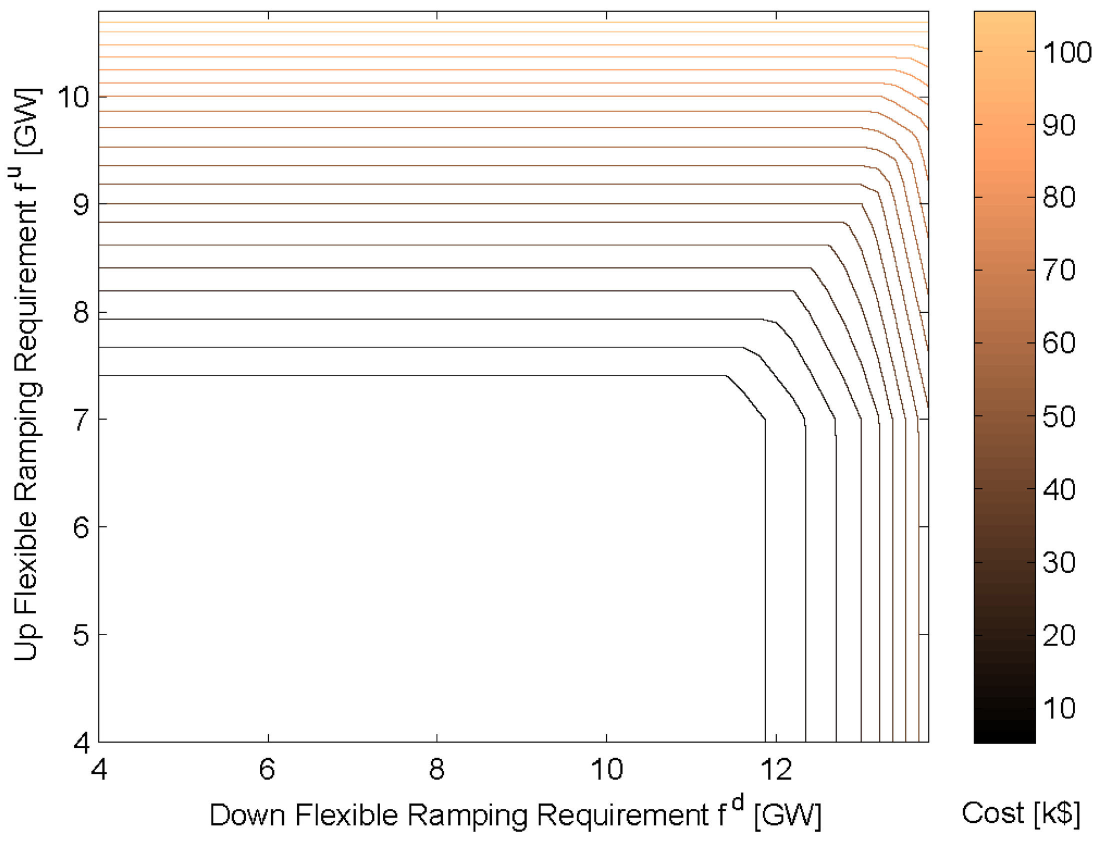
$$\mathrm{DS}(f^d, f^u) = \mathrm{MinC}(f^d, f^u) - \mathrm{MinC}(0,0)$$

Greedy Approach: Select the shortest interval that achieves the risk-limiting constraint

$$\min_{f^d, f^u} f^d + f^u$$

$$s.t.\ \Pr\{-f^d \le d^t - \hat{d}^t \le f^u\} \ge p, \forall t$$





Dashed Red Line: Greedy Approach

Solid Blue Line: Our Approach