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A New Wholesale Bidding Mechanism for Enhanced Demand response in Smart Grids

- Background and Problem Statement
- Existing Solutions
- Proposed Solution
  - Solution Description
  - Implementation Method
  - Application Effects
- Summary

Demand response (DR) programs in deregulated electricity markets cause multiple problems

- Short-term problems
  - Demand forecasting
  - Generation dispatching
  - Day-ahead and real-time price settlement
  - …
- Long-term problems
  - Demand forecasting
  - Plants and transmission network's allocation
  - Cost estimation
  - …

The design and implementation of demand response programs are also affected by the operation of their electricity markets.

Three traditional demand responsive bidding mechanisms

- Emergency Demand Side Bidding (EDSB)
- Shortcomings
  - Uncoupled with regular electricity markets
  - Not considering demand-side benefits
  - Limited demand-side participation…

1. Registered generators and retailers submit bids.

$$B_t^i = < P_t, p(P_t) > , t \in T, i \in \mathcal{D}$$

2. The market operator solves for the market clearing prices and quantities.

$$min \sum_t^T (\sum_j^{NG} C^j(P_t^j, u_t^j) + \sum_i^{ND} C^i(P_t^i, u_t^i)) , i \in \mathcal{D}, j \in \mathcal{G}$$

3. Accepted bids are settled at the market clearing prices at the emergent periods. Extra rewards may be settled annually.

- Single Hourly Bidding (SHB)
- Improvements on EDSB
  - Regular operation and reduction of market power
  - Larger social surplus
  - More demand-side participation
  - Efficient equilibrium in DA market
- Shortcomings
  - Ignoring loads' operating constraints and end-user shiftability

1. Generators and retailers submit bids.
2. The market operator solves for the market clearing prices and quantities.

$$max \sum_t^T (\sum_i^{ND} B^i(P_t^i, u_t^i) - \sum_j^{NG} C^j(P_t^j, u_t^j)), i \in \mathcal{D}, j \in \mathcal{G}$$

3. Accepted bids are settled at the market clearing prices across the day, and the bidding results are announced.

- A bidding mechanism proposed by Su and Kirschen
- Improvements on SHB and EDSB
  - Considering loads' inter-temporal constraints
- Shortcomings
  - Shiftability described by ramping limits for neighboring hours
  - Requiring specific physical characteristics of loads
  - Computation difficulties and low optimality level of the solution

1. Generators and retailers submit bids.

$$B_T^m = < P_t, p(P_t), P_{rp}, E_{max,T}, P_{max}, P_{min} | t \in T >, m \in \mathcal{M}$$

Modeling demand response with Price Elasticity Matrices (PEM)

- Electricity of all time-periods are treated as products that substitute or complement each other

$$\widetilde{\epsilon_{t\tau}} = \frac{\partial P_t / P_t}{\partial p_\tau / p_\tau}$$

- During a timeframe *T*, all time-period price influences on electricity demand are modeled by PEM as

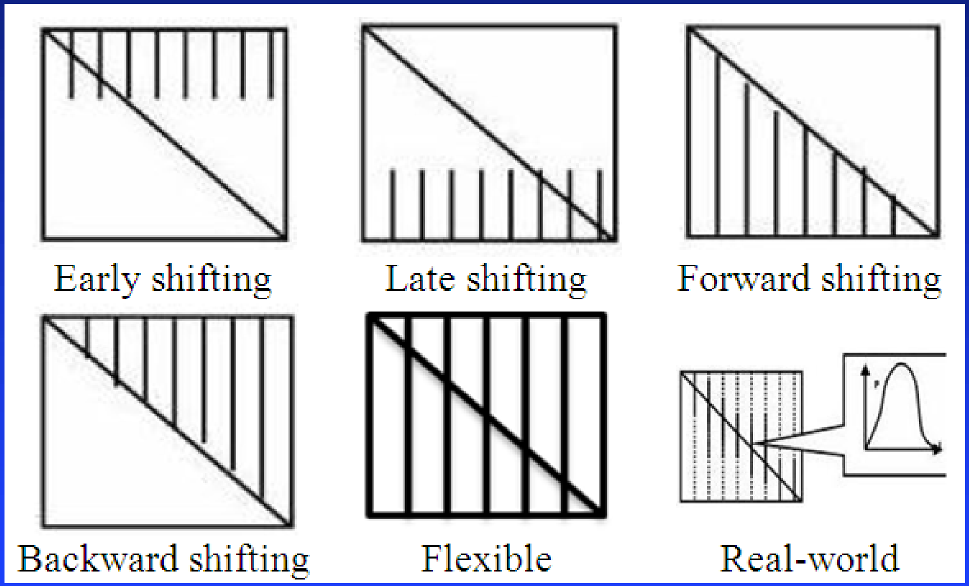
$$\varepsilon_{T\times T} = \begin{bmatrix} \epsilon_{11} & \epsilon_{11} & \cdots & \epsilon_{1T} \\ \epsilon_{21} & \epsilon_{22} & \cdots & \epsilon_{2T} \\ \vdots & \vdots & \ddots & \vdots \\ \epsilon_{T1} & \epsilon_{T2} & \cdots & \epsilon_{TT} \end{bmatrix}$$

- Describing loads' characteristics by PEM

$$\sum_t \epsilon_{t\tau} = 0$$

Summarizing demand response patterns by Price Elasticity Matrices (PEM)'s topologies

- Three categories of loads
  - Fixed loads
  - Curtailable loads
  - Shiftable loads
- End-user types of shiftable loads and their PEMs



The proposed bidding mechanism with demand response modeled by PEMs

- DA auction process

1. Generators and retailers submit bids.

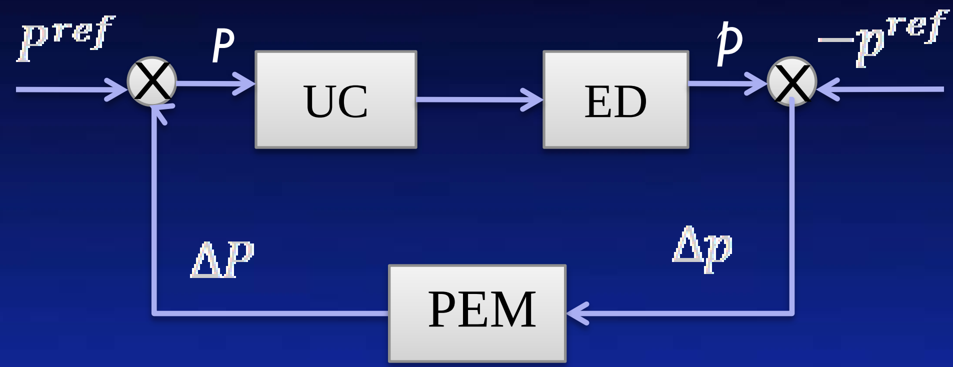
$$B_T^r = < P_t^{ref}, p_t^{ref}, \varepsilon_{T \times T} | t \in T >, r \in \mathcal{R}$$

2. The market operator solves for the market clearing prices and quantities.
3. Accepted bids are settled at the market clearing prices across the day, and the bidding results are announced.

price at node *i* =
[marginal social cost of demand at swing bus]
x [1+ incremental losses caused by *i*]
+ [transmission constraints over all lines]

A market-interaction algorithm proposed by David and Kirschen

- The algorithm's basic structure

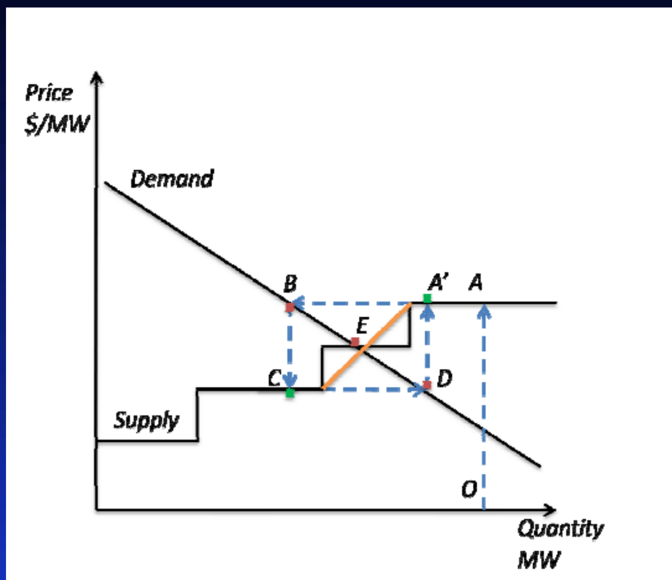


- An extension of the algorithm

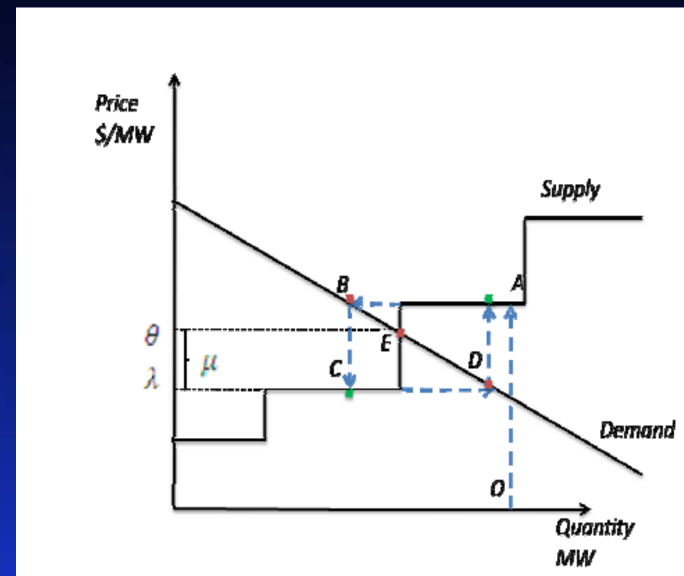
  Paralleled feedback branches for multiple retailers

The basic algorithm cannot guarantee convergence under two cases

- Steep demand curve



- Demand clears the market



  – Originate the definition of relative slope

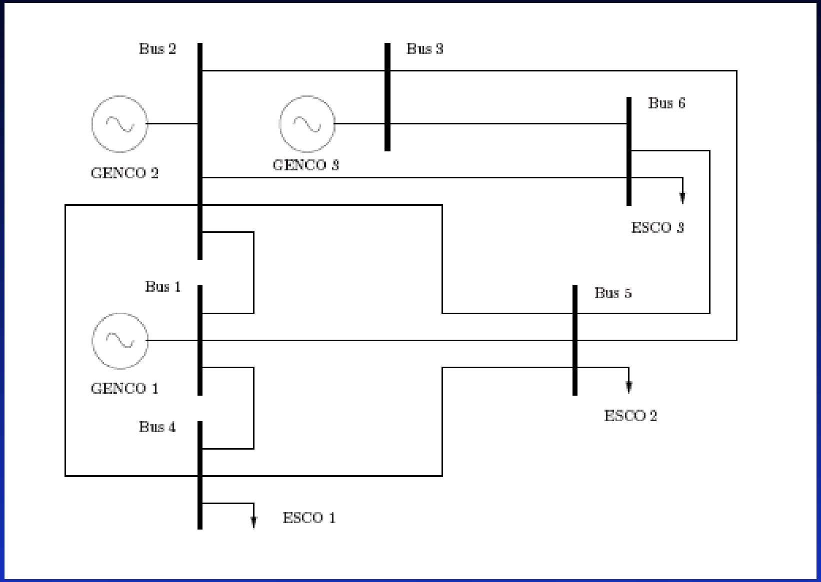
$$k \le k_{A,C} \qquad (52\ b)$$

and

$$k_{A,C} = \frac{\lambda(G_A) - D_k^{-1}\left(\underline{cap}(G_A)\right)}{\underline{cap}(G_A) - D_k(\lambda(G_A))}, \qquad (52\ c)$$

Testing the bidding mechanism under sudden loss of generation capacity

- A 6-bus testing system



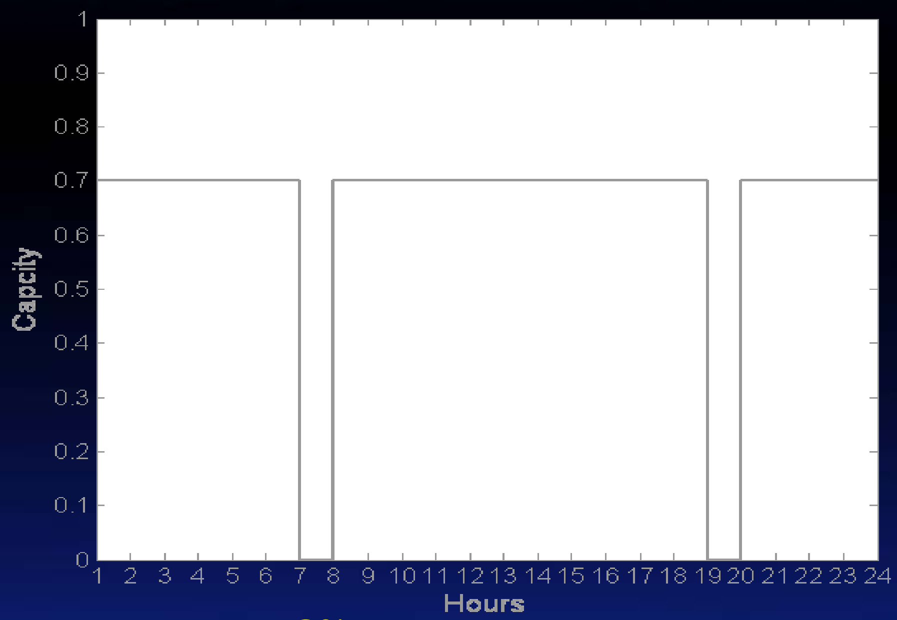
- Base unit G1 (1.0,9.8)
- Shoulder unit G2 (0.7,10.7)
- Peak unit G3 (0.5,12.6)

- Reference data

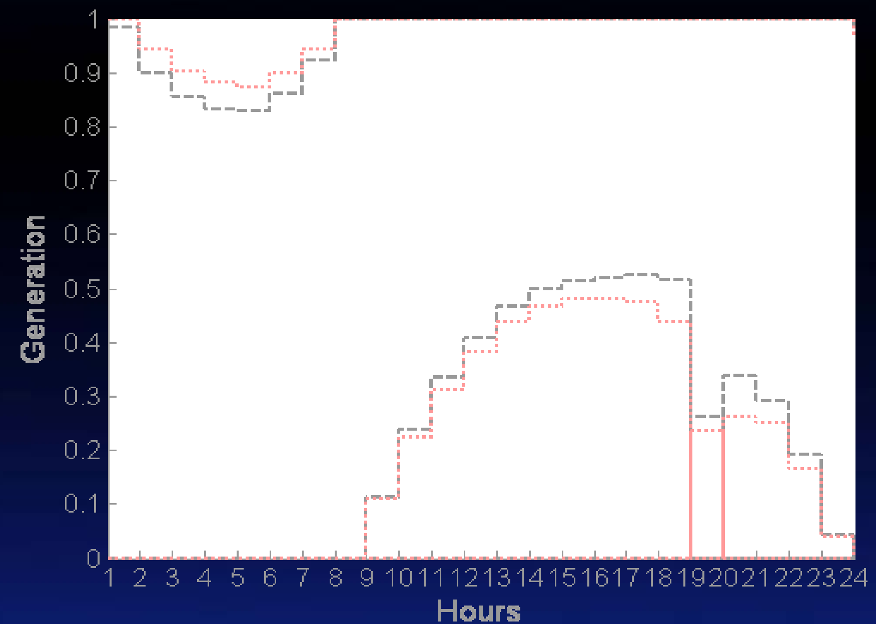
  Long Island, New York State on August 9, 2008

- Customer types

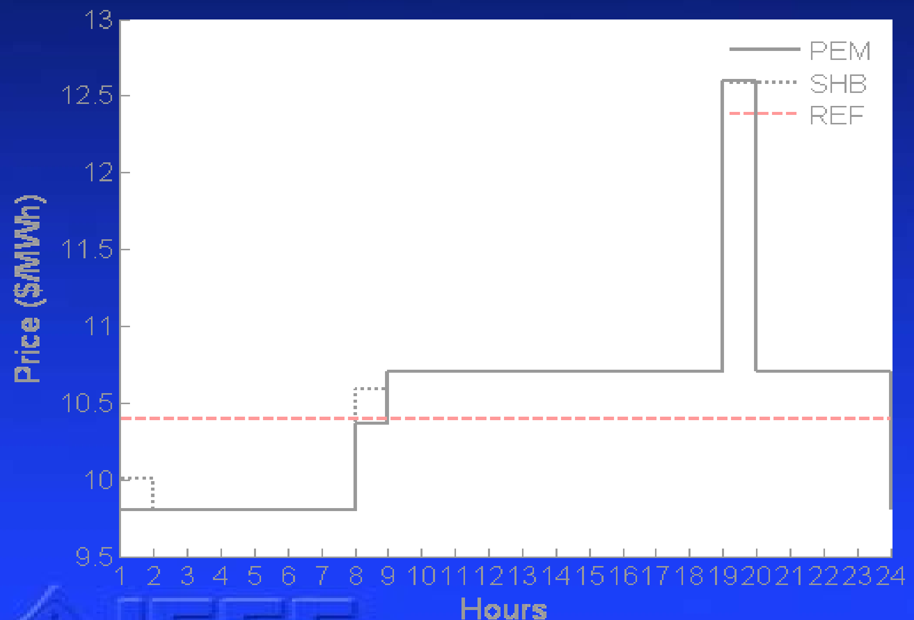
  Real-world end users



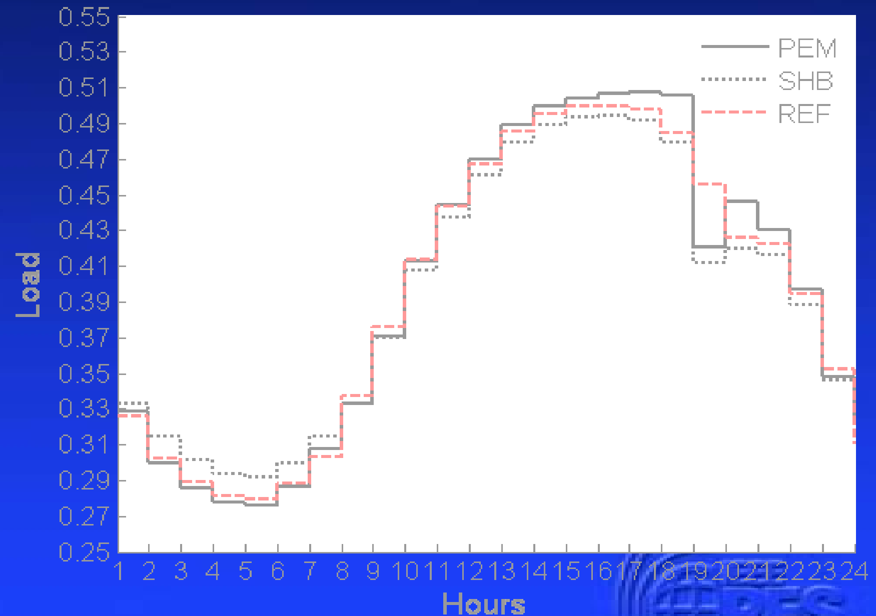
G2's generation capacity



the three generators' dispatching schedule



market clearing price



final estimated load profile with demand response

The proposed bidding mechanism has multiple advantages over the traditional ones

- Modeling demand response with ease and compactness
- Allowing real-time updating of the demand response model
- Describing loads' constraints and end-user shiftbility
- Considering inter-temporal constraints
- Can be implemented under various DR programs
- Less and easier computation
- More optimal and realistic solutions

Summary

- Background and Problem Statement
  - Problems caused by DR under deregulated electricity markets
- Existing Solutions
  - The principle, advantages and shortcomings of three traditional bidding mechanisms: EDSB, SHB and Su's bidding
- Proposed Solution
  - The definition and properties of PEMs
  - The proposed bidding with PEM to model end-user response
  - The market clearing structure of the proposed bidding obeys the optimal spot pricing structure and identical for all end-user types
  - A algorithm considering two non-convergent causes and relative slope
  - Testing of the proposed bidding under cases of sudden loss of generation capacity and sudden change of generation cost
  - The benefits of applying the proposed bidding mechanism