A Market Mechanism for Efficient Bidding with Energy Storage

Rajni Kant Bansal, Pengcheng You, Dennice F. Gayme, Enrique Mallada
Johns Hopkins University

Motivation and Prior Works

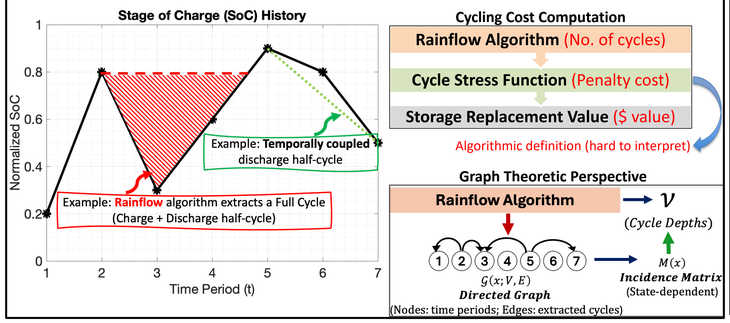
- Canonical market designs ignore unique resource attributes
- FERC 2222 calls for democratized participation in markets
- Existing research broadly follow two categories:
  - Operator centric: Reveal private information[1]; Inflexibility in profit seeking
  - Resource centric: Exogenous market signals[2]; No theoretical guarantees

Goal and Contributions

- Novel market design - accounts for unique characteristics
- Incentive alignment - across heterogeneous participants

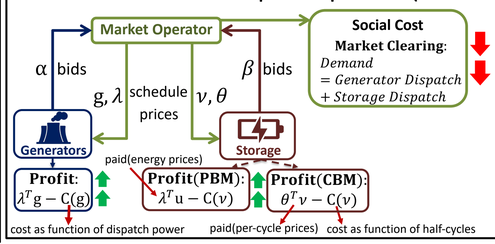
Storage Cycling Cost

- Function of coupled charge-discharge half-cycles



Market Model

- Storage Bids:
  - Prosumer-Based Model (PBM): Bids based on charge-discharge power ($u = \beta\lambda$)
  - Cycle-Aware Model (CBM): Bids based on charge-discharge half-cycles ($v = \gamma\theta + \beta$)
- Generator bids dispatch power (linear supply function) in both cases ($g = \alpha\lambda$)



Participation Behavior

- Price-taking participants: Competitive equilibrium
- Price-anticipating participants: Nash equilibrium

Bidding Behavior

- Uniform Bid: Scalar variable for entire time horizon
- Non-uniform Bid: Vector variable for each period

Analysis - Competitive Equilibrium

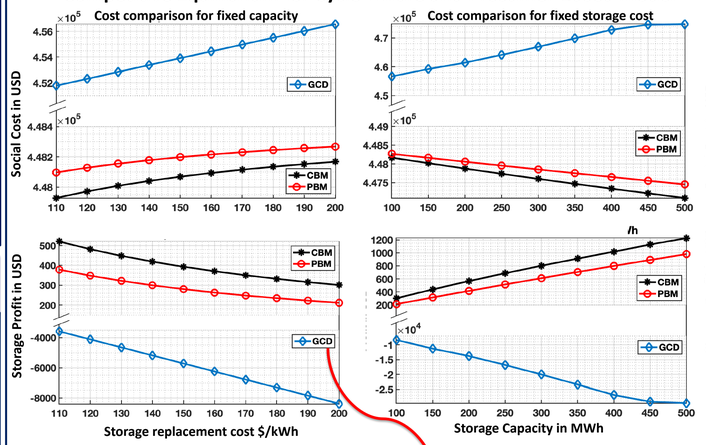
- **Theorem 1** (informal)**:** Uniform bidding
  - The equilibrium in the prosumer-based market (PBM: both storage and generator bids power) exists uniquely.
  - Further, it is incentive-aligned iff the gradient of storage cycling cost is proportional to demand.
- The above condition is not generally satisfied; mismatch between operator and resource
- **Theorem 2** (informal)**:** Uniform bidding
  - The equilibrium in the cycle-aware market (CBM: storage bids cycle depths, generator bids power) exists uniquely.
  - Furthermore, the equilibrium is efficient and incentive-aligned, i.e., solves the social planner problem.

Analysis - Nash Equilibrium

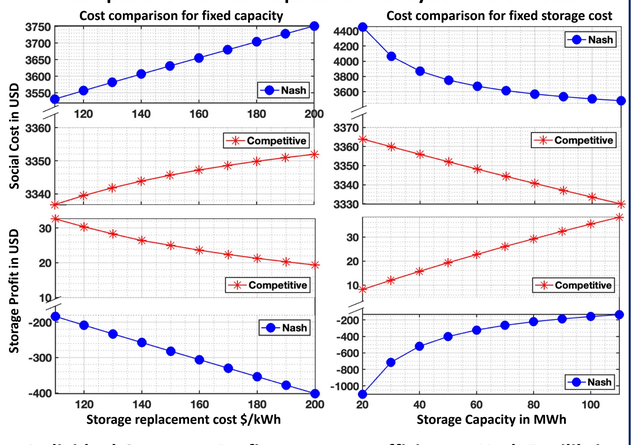
- **Theorem 3** (informal)**:** Uniform bidding
  - A partially symmetric equilibrium (storage units are homogeneous and take symmetric decision) exists uniquely.
  - The partially symmetric equilibrium aligns with the social planner asymptotically, i.e., market recovers efficiency losses.
- Increase in number of participants in either group helps counter the market power of all
- **Theorem 4** (informal)**:** Non-uniform bidding
  - A partially symmetric equilibrium aligns with the social planner asymptotically, i.e., market recovers efficiency losses.

Numerical Validation - Uniform Bidding

Competitive Equilibrium for Cycle-Aware and Prosumer-Based model

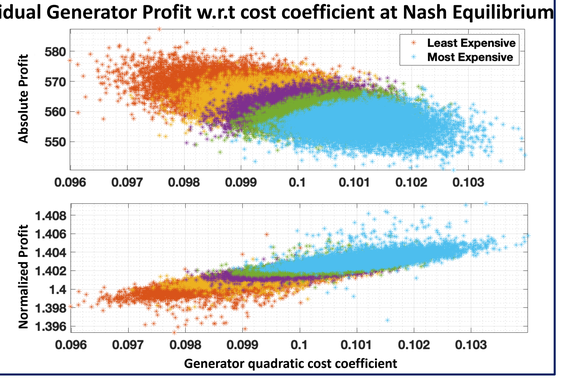


Competitive and Nash Equilibrium for Cycle-Aware Model



- Benchmark - current practice: ***(GCD)*** *Generation Centric Dispatch*: Social cost = generation + *(hidden)* cycling cost;
- CBM earns higher profit and results in lower social cost at competitive equilibrium
- Storage is exploited in market at Nash equilibrium
  - High storage replacement cost; dependence on generator for charging
- Expensive generators earns higher normalized profit

Individual Generator Profit w.r.t cost coefficient at Nash Equilibrium



References

[1] S. Wogrin and D. F. Gayme, "Optimizing Storage Siting, Sizing, and Technology Portfolios in Transmission-Constrained Networks," in *IEEE Transactions on Power Systems*, 2015.

[2] B. Xu, J. Zhao, T. Zheng, E. Litvinov and D. S. Kirschen,"Factoring the Cycle Aging Cost of Batteries Participating in Electricity Markets," in *IEEE Transactions on Power Systems*, 2018.

[3] **R. K. Bansal, P. You, D. F. Gayme, and E. Mallada,** "A market mechanism for truthful bidding with energy storage", Electric Power Systems Research (EPSR), vol. 211, no. 108284, pp. 1–7, Jul. 2022, also in Power Systems Computation Conference (PSCC), 2022

[4] **R. K. Bansal, P. You, D. F. Gayme, and E. Mallada,** "Intercept Supply Function and Energy-Cycling Function Bidding in Electricity Markets" in preparation.

JOHNS HOPKINS UNIVERSITY

Award ID#: 2136324 JHU