IJCAI JEJU 2024

Optimizing Prosumer Policies in Periodic Double Auctions Inspired by Equilibrium Analysis

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Aug 6, 2024

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Motivation

Motivation

- The Periodic Double Auction[1] is made up of **Suppliers** and **Consumers**.
- **Objective** is to find **Policies** for the consumers to **Minimize the Cost**.
- Application of PDA is that it models a Day Ahead Electricity Market.
- Hence, the developed policies can be used in the Market.

[1] It is denoted as PDA.

Day Ahead Electricity market

- Day Ahead Electricity Market has two components: Suppliers and Cosumers.
- When Consumers are allowed to sell small quantities, they are called as **Prosumers**.

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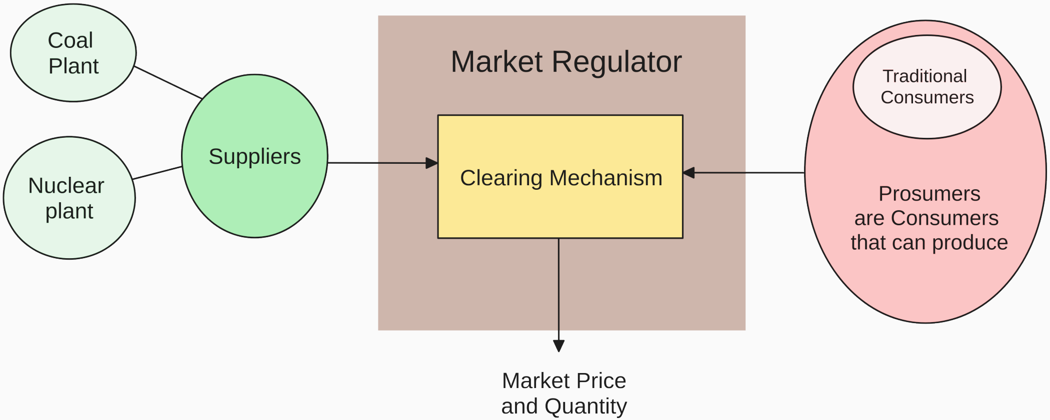
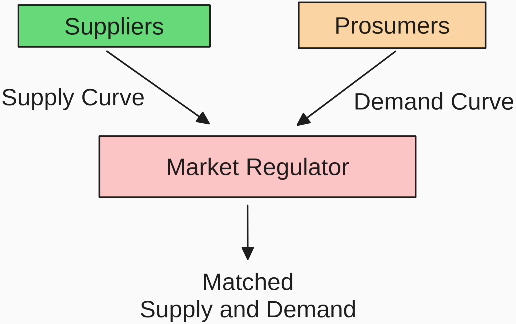

Coal Plant
Nuclear plant
Suppliers
Market Regulator
Clearing Mechanism
Traditional Consumers
Prosumers are Consumers that can produce
Market Price and Quantity

Introduction

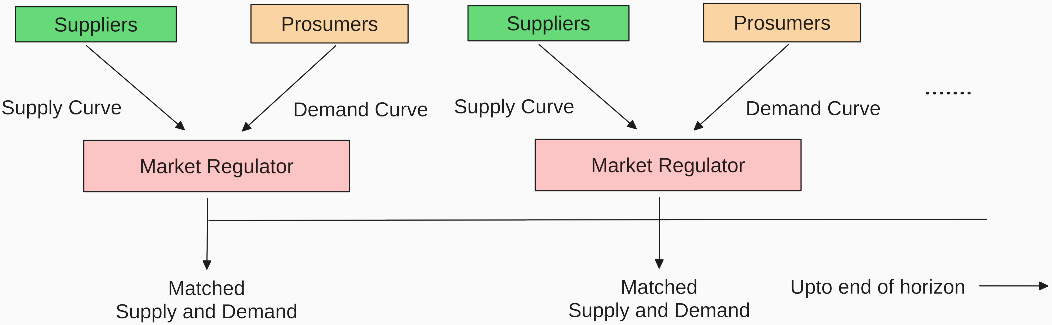
Double Auction

- **Double Auction** is where the Suppliers and Prosumers are strategic.
- A Market Regulator matches the asks by supplier with the bids by the Prosumers.
- Both Asks and Bids are the pair of price and quantity.



PDA

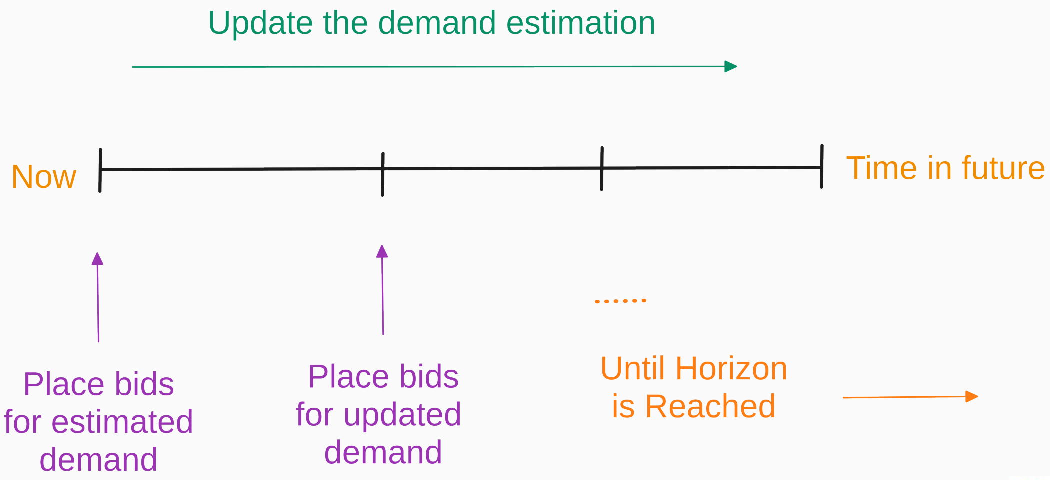
The PDA is the sequence of Double Auctions and it has a finite horizon.


Suppliers
Prosumers
Suppliers
Prosumers
Supply Curve
Demand Curve
Supply Curve
Demand Curve
....
Market Regulator
Market Regulator
Matched
Supply and Demand
Matched
Supply and Demand
Upto end of horizon

Problem Statement

Problem Statement

The goal is to find **policies** for the **Prosumers** to minimize the **procurement cost**.


Update the demand estimation
Now
Time in future
Place bids for estimated demand
Place bids for updated demand
......
Until Horizon is Reached

Solution Approach

- The PDA is modeled as a **Markov game**.
- A **Nash equilibrium** (NE) is formulated in an ideal setting[2].
- Based on the NE analysis, an algorithm for the policy is developed.

[2] Some assumptions were made on the game to get to the NE.

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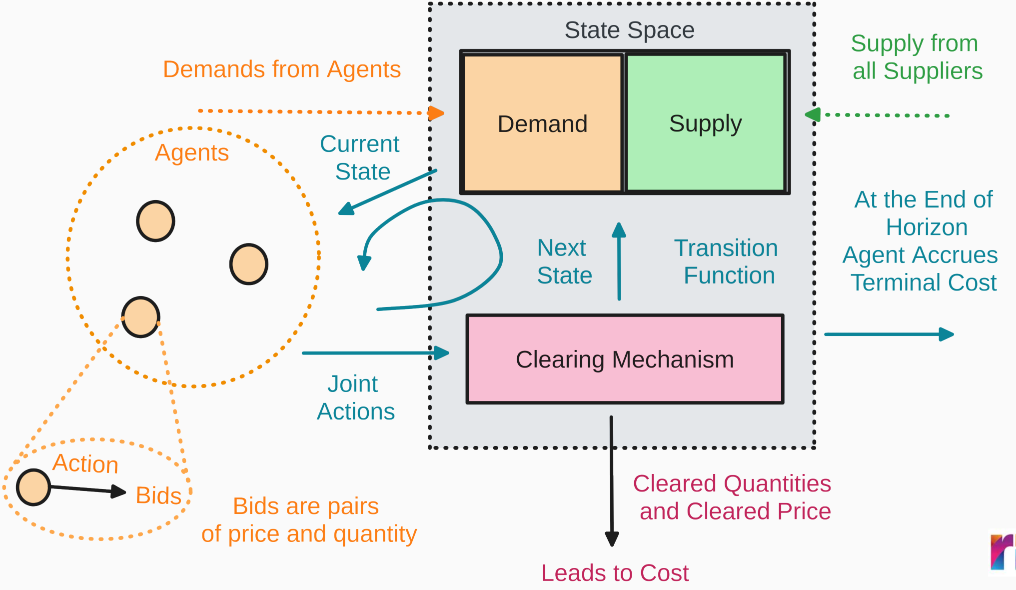
Modeling PDA as a Markov Game

Modeling PDA as a Markov Game

The PDA is modeled as a **Markov Game** $\mathcal{M} = \langle N, A, S, P, C, H \rangle$


State Space
Demands from Agents
Demand
Supply
Supply from
all Suppliers
Agents
Current
State
Next
State
Transition
Function
At the End of
Horizon
Agent Accrues
Terminal Cost
Clearing Mechanism
Joint
Actions
Action
Bids
Bids are pairs
of price and quantity
Cleared Quantities
and Cleared Price
Leads to Cost

Procurement Cost

- The procurement cost is the **sum of costs** in each of the rounds.
- Starting from a state $s \in S$, the procurement cost is denoted as $V(s)$.
- $V(s)$ is also called as the Value function.

Nash Equilibrium

Nash Equilibrium

NE is a joint policy $a \in A$, in which no agent can **unilaterally deviate** from the alloted action.

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Insights from the Equilibrium Policy

- If there **are enough rounds** for players, then they would want to **utilize the rounds**.
- If rounds are not enough, then the players would bid at maximum possible price to **avoid paying very high price** outside the auction.
- The policy suggests the players **with higher requirement have more leverage**.

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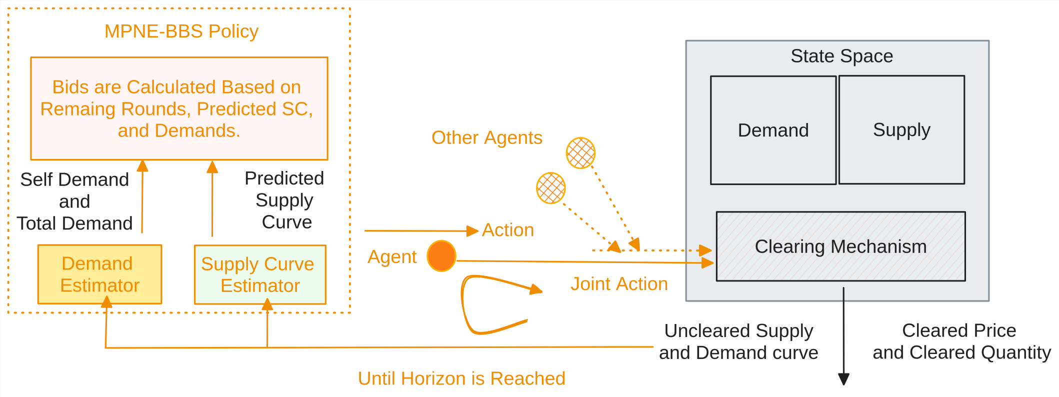
MPNE-BBS : An Algorithm Based on Nash Equilibrium Analysis

Algorithm 1 MPNE-BBS

totalDmd[] $\leftarrow$ **netDmdPredict**(time)
selfDmd[] $\leftarrow$ **indvDmdPredictor**(time)
for hour in $[1, \ldots, 23]$ **do**
    deliverySlot $\leftarrow$ time $+$ hour
    unclearedAsks[] $\leftarrow$ **Auction**(time-1,deliverySlot)
    estBidPrice $=$ **getEstBidPrice**(time,deliverySlot,unclearedAks,selfDmd,totalDmd)
    adjEstBidPrice $=$ **getAdjEstBidPrice**(estBidPrice) *To account for inaccurate SC*
    bidList $=$ **getBids**(adjEstBidPrice)
    Auction(time,deliverySlot) $\leftarrow$ bidList

Algorithm 2 getEstBidPrice (time,deliverySlot,unclearedAks,selfDmd,totalDmd)

if unclearedAsks is not empty **then**
  supplyQty $\leftarrow$ sum(unclearedAsks.quant)
  if supplyQty $>$ totalDmdForDSlot **then**
    $p_{u_h} \leftarrow$ Lowest price at which totalDmd[deliverySlot] can be cleared
    qtyReqForOthers $\leftarrow$ totalDmd[deliverySlot] - selfDmd[deliverySlot]
    $p_{v_h^b} \leftarrow$ Lowest price at which qtyReqForOthers can be cleared
  else
    $p_{u_h}, p_{v_h^b} \leftarrow$ Maximum Ask Price
  $v_h^0 \leftarrow \max\{1, u_h - \text{hour} + 1\}$ *To get remaining rounds*
  return estBidPrice $= \max\{p_{v_h^0}, p_{v_h^b}\}$ *Adjust price to account for remaining rounds*
else
  clearedPrices[] $\leftarrow$ Auction(t,t+hour) $\forall t <$ currentTime
  return estBidPrice $= \max\{$cleredPrices$\}$


MPNE-BBS Policy
Bids are Calculated Based on Remaing Rounds, Predicted SC, and Demands.
Self Demand and Total Demand
Predicted Supply Curve
Demand Estimator
Supply Curve Estimator
Other Agents
Action
Agent
Joint Action
State Space
Demand
Supply
Clearing Mechanism
Uncleared Supply and Demand curve
Cleared Price and Cleared Quantity
Until Horizon is Reached

Results

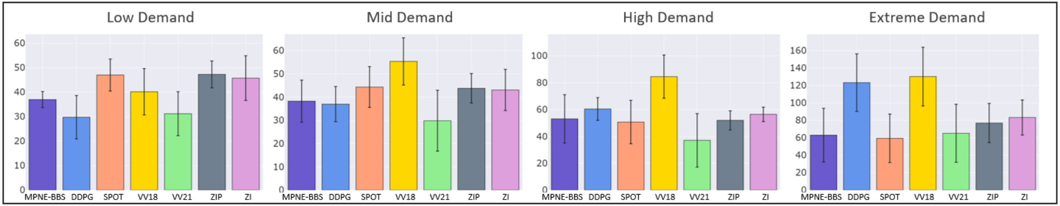


Figure 1: Wholesale Cost Comparison in 7-Player Games[3]

[3]Chandlekar et al. [2],Chandlekar et al. [1],Chowdhury et al. [3],Ghosh et al. [5],Cliff [4]

Conclusion

- A Nash Equilibrium for a PDA modeled as Markov game is devised.
- This Equilibrium helps in explaining the policy of the players in different scenarios.
- Devised an algorithm based on the Nash Equilibrium Analysis, results show that it works well in practice.
- In future work, aim is to extend the analysis to partial observable setting and see how it can help in devising algorithms.

For further discussion, please visit my poster presentation.

Thank You

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- Sanjay Chandlekar et al. “VidyutVanika21: An Autonomous Intelligent Broker for Smart-grids”. In: *Proceedings of the Thirty-First International Joint Conference on Artificial Intelligence, IJCAI-22*. July 2022, pp. 158–164. DOI: 10.24963/ijcai.2022/23. URL: https://doi.org/10.24963/ijcai.2022/23.
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Dave Cliff. *Minimal-Intelligence Agents for Bargaining Behaviors in Market-Based Environments*. Technical Report HPL-97-91, Hewlett Packard Labs., 1997.

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