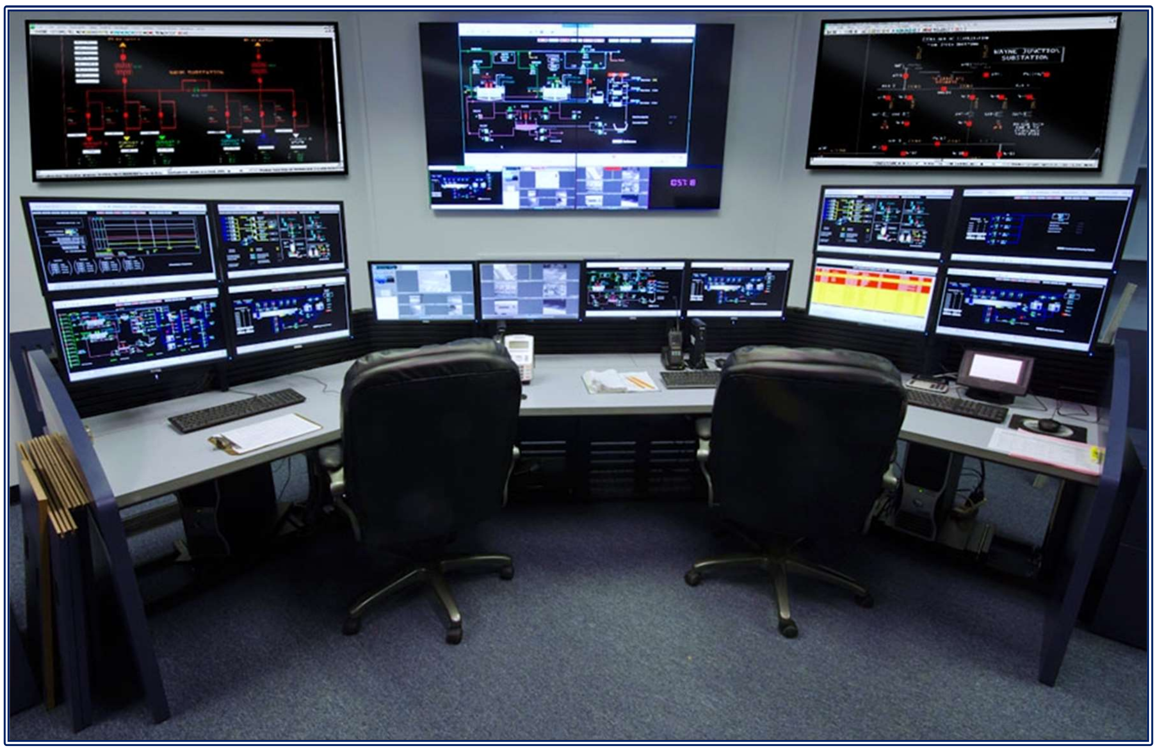
SALIENT DETAILS
OF
PRICE DISCOVERY ALGORITHM



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1.0 Price Discovery Algorithms across different contracts

The different contracts presently being offered at HPX platform along with their price discovery methodology is summarized in the Table below:

Market Segment	Contract	Price Discovery Methodology
Integrated Day Ahead Market (IDAM)	Day Ahead Contract/ Green Day Ahead Contract	Double sided closed bid uniform price auction with congestion management module
Real Time Market (RTM)	Real Time Market Contract	Double sided closed bid uniform price auction with congestion management module
Intra and Day Ahead Contingency	Contingency Contract	Continuous Matching
Term Ahead Market (TAM) / Green Term Ahead Market (GTAM)	Daily Contracts	Uniform Priced Step Open Auction
	Weekly Contracts	
Renewable Energy Certificates Market (RECs)	Renewable Energy Certificates Contracts	Double sided closed bid uniform price step auction
Energy Savings Certificate (EScert) Market	Energy Savings Certificate Contracts	Double sided closed bid uniform price step auction

Table 1: Price Discovery Methodology across different segment/contracts

The algorithms of above methodologies have been discussed in detail in the subsequent sections.

1.1 Double sided close bid uniform price auction:

The double-sided closed bid uniform price auction mechanism is administered for price discovery in the IDAM and RTM segments which are based on principles of collective transactions. The buyers and sellers submit their bids during the market hours based on which the market clearing engine discovers the Market Clearing Price (MCP) and Market Clearing Volume (MCV) upon closure of the market. The details of the bid types and algorithm used for the price discovery are discussed in the sections below.

Bid Types: The different bid types available for trading in IDAM and RTM segment are as follows:

1.1.1. Single Bid: Single bid allows the market participants to specify multiple sequences of price and quantity pairs in a portfolio manner. The quantity varies linearly between two price pairs.

1.1.2. Block Bid: Block bid allows the market participants to specify one price and one quantity for a combination of continuous 15-minute time blocks. Selection criterion is average of Area Clearing Price (ACP) for the quoted 15-minute time blocks of the respective client's bid area. It is an 'All or None' type of order.

1.1.3. Minimum Quantity Block Bid: Minimum Quantity Block Bids allows the market participants to specify one price and one quantity for a combination of continuous 15-minute time blocks along with a 'Minimum Quantity percentage' and additional quantity out of remaining bid volume are cleared in the volume steps of 0.01 MW.

1.1.4. Profile Block Bid: Profile Block bid allows the market participants to specify one price and varying quantities for a combination of continuous 15-minute time blocks. Selection criterion is based on weighted average of ACP for the quoted 15-minute time blocks of the respective client's bid area. It is an 'All or None' type of order.

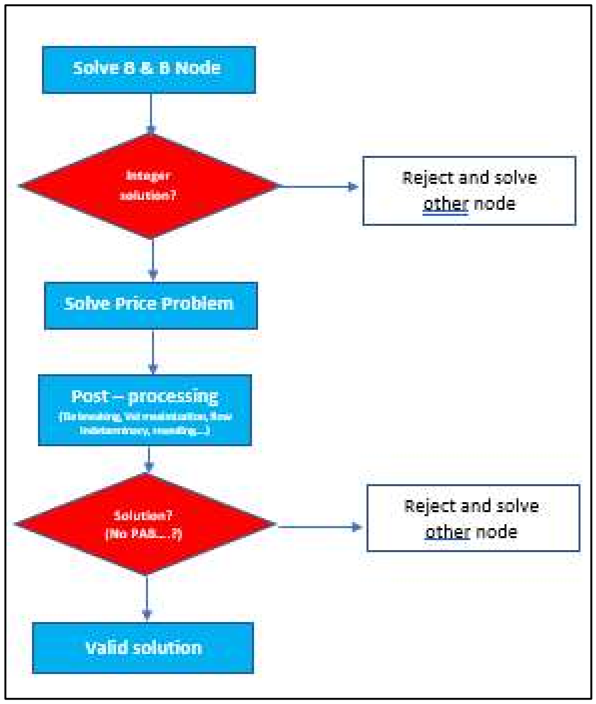
1.1.5. Linked Bid: In the linked bid two different block bids can be linked as parent and child bid. The child bid is considered for selection only when the parent bid is selected. Both the bids are selected if the combined value obtained from parent and child bid is found to be positive.

<u>Algorithm for Price Discovery:</u>

The pricing algorithm of Day Ahead Market (DAM) & Real Time Market (RTM) is based on a closed double-sided auction with uniform market clearing prices and aims to maximize the social welfare. The algorithm is made to solve uniform pricing double-sided close-gate auction under network constraints. Formally,

- Uniform means that the market price must be the same in all bidding areas linked by a non – congested network path.
- Double-sided means that some sellers reveal their production costs through selling bids, while buyers express their willingness to pay via buying bids.
- Close gate means that all bids must be submitted upfront a certain timeline before the matching engine establish a MCV & MCP for the market.

1.1.1 Algorithm Overview



1.1.2 Welfare maximization:

The goal of the algorithm is to find the selection of bids that maximizes the social welfare of the market participants. The social welfare is the sum of the surpluses of all the market participants and the congestion rent of the Transmission System Operator (TSO). In other words,

• The surplus of a sell bid is the difference between the revenue generated by the traded quantity and the associated cost of production.

• The surplus of a buy bid is the difference between the value generated by the traded quantity and the cost of the trade.

• The congestion revenue is the money which arises due to the different price formation in different areas (Deficit area and surplus area).

Figure 1 illustrates how this can be represented on a classic offer and demand microeconomics graph when market equilibrium is reached. Remember that an equilibrium is defined as a price such that the quantity demanded by consumers at that price is balanced by the quantity offered by producers at that price and is thus the crossing point of the supply and demand curves.

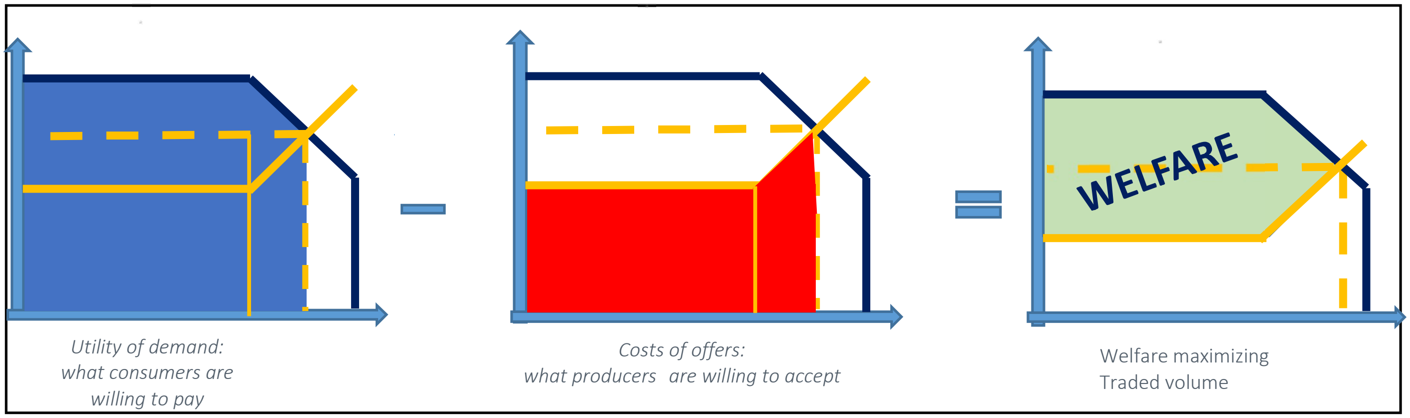


Figure 1 Welfare maximization

Above figure representation of the welfare as the revenues of the buy bids minus the costs of the sell bids or as the sum of the producer surplus (orange area) and consumer surplus (blue area). There is no TSO congestion rent as a single market is considered.

Welfare maximization is an interesting criterion as it ensures to reach a competitive market equilibrium which is Pareto efficient. A situation is called Pareto optimal or Pareto efficient if no change could lead to improved satisfaction for some agent without some other agent losing satisfaction. This guarantees that the most efficient producers (i.e., with the lowest production costs) provide their goods to the buyers with the highest utility (i.e., creating the most value out of the matched quantity). The welfare maximization mechanism also benefits from a second noticeable property: it ensures that a Nash equilibrium is reached. Indeed, market participants receive the incentive to bid their actual cost, or their actual valuation of the commodity (depending on if they are buyers or sellers) and not to enter some gaming strategies. This feature is interesting for the market operator who knows that he is able to run an efficient market without have to worry about the internal constraints and profits of every market participant.

1.1.3 Welfare maximization and volume maximization

Maximizing the welfare tends to clear as much volume as possible while the prices of the buyers and sellers are compatible. However, in the presence of block bids, welfare maximization is not equivalent to cleared volume maximization. That is because the welfare depends on the cleared volume and on the bid prices. Figure 2 represents an order book of block bids for which welfare maximization is not equivalent to volume maximization. First observe that it is not possible to accept all bids together as there exists no common market price that would satisfy buy block bid 2 and sell block bid 1 simultaneously. Therefore, we must choose between

- Accepting buy block bid 1 and sell block bid 1 only. The matched volume is 10 MW, and the welfare is 1500 INR.
- Accepting buy block bid 2 and sell block bid 2 only. The matched volume is 20 MW, and the welfare is 1000 INR.

From this example, it is thus obvious that the welfare maximizing solution is not always the volume maximizing solution.

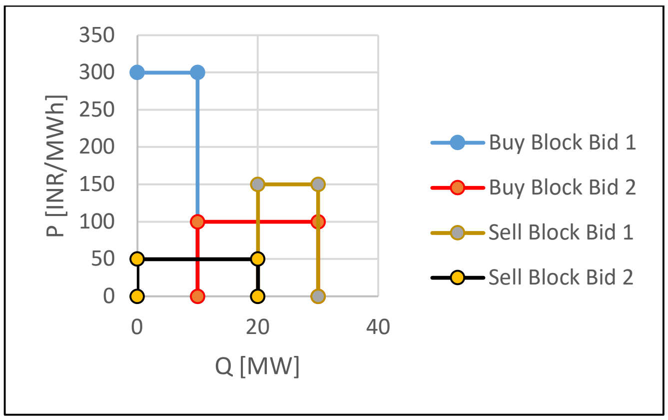


Figure 2: An order book of block bids for which volume maximization is not equivalent to welfare maximization. All block bids have a minimum acceptance ratio of 1.

1.1.4. <u>Distance to optimality (gap) and Branch and Bound (B&B)</u>

The welfare maximization problem is a Mixed Integer Problem (MIP). Integer variables (more precisely binary variables) are needed to model the fill-or-kill property of the block bids. MIP problems are known to be hard to solve. Nonetheless, solving the relaxation of the MIP where all binary variables are allowed to take continuous values is a much easier problem. The solution to this relaxed problem provides an upper bound (UB) on the best welfare that can potentially be achieved. This solution however is very likely to violate the binary conditions as they were relaxed. If by any chance the binary conditions are satisfied, the optimal solution is found. When the binary conditions are not satisfied, we pick one of those and create two new child nodes to the current relaxation: one node where the binary variable is forced to be 0 and one node where the binary variable is forced to be 1 (this is referred to as branching). Solving the two nodes provides a new upper bound for the best welfare that can be reached and a feasible solution in case one of the nodes satisfies the binary conditions. For each of the child nodes, if the solution does not satisfy the binary conditions, we create again two child nodes by branching on another binary variable. The approach is repeated as long as new nodes are created. This process is called a Branch and Bound (B&B).

In conclusion, the algorithm continuously updates its best solution found and its upper bound while searching for better solutions by diving deeper and deeper into the tree. By doing this, it gains in flexibility and reliability by ensuring it will give the best outcome possible if a problem occurs to reach the best solution, or simply because a time limit is reached without arriving at the end of the tree. To offer an overview of the performance of the algorithm, an optimality gap (i.e., an upper bound on the difference between the welfare of the best undiscovered solution and the welfare of the best discovered solution) is computed at the end of the computations. The computation is done by comparing the welfare of the best feasible solution found with the often better but unrealistic (because binary constraints are violated) welfare of the relaxations solved at the various nodes of the branching tree. This upper bound can therefore be seen as a trustful value which does not depend on any statistical estimation. If sufficient time is given to the Branch and Bound process, the optimality gap is reduced to 0 as the algorithm should have time to explore all the created nodes.

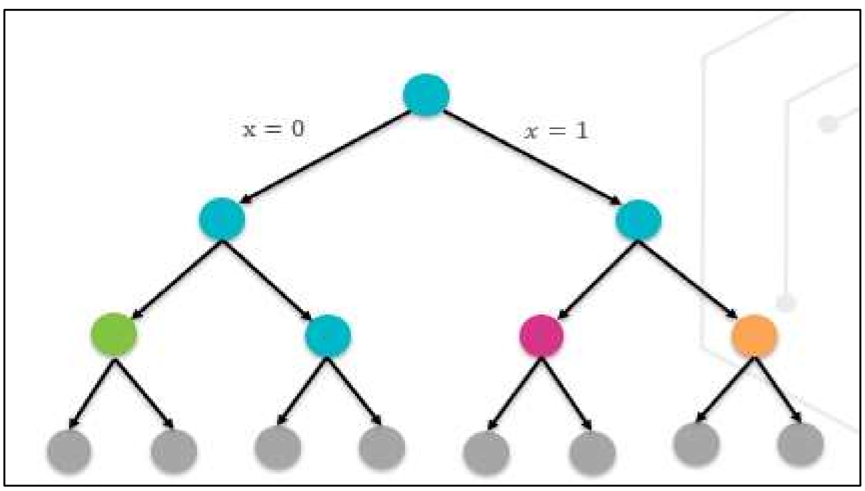


Figure 3: Branch and Bound algorithm as key tool to solve the Mixed Integer Programs

1.1.5. Bid types

This section describes the various types of bids supported by the HPX Matching engine.

1.1.5.1. Single bids

This section generalizes the modelling of single bids to the case where the curves can contain both supply and demand. Single bids (also known as interpolated curves) are simple linear orders. Each single bid defines a set of quantity-price points. At quantities falling in between two points, the price is linearly interpolated. Single bids thus define a piecewise linear price function Negative quantities correspond to supply, whereas positive quantities correspond to demand. Single bids can be two-sided, in the sense that they can contain both positive and negative quantities. The single bids must fulfil the following requirement: quantities should be non-increasing, and price should be non-decreasing, except for segment at minimum and maximum prices. In other words, horizontal segments are forbidden except at minimum market price maximum price.

Figure 4 shows examples of single bids. On the left are displayed sell-only and buy-only single bids. On the right, it is a display of bid containing both supply and demand, crossing the 0 MW quantity close to 8000INR/MWh.

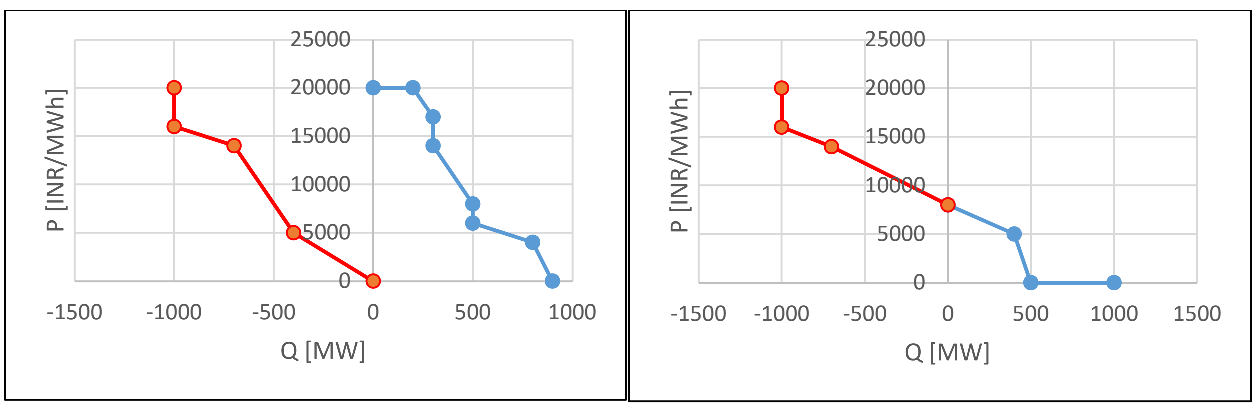


Fig 4: Examples of Single bids

Example:

Let's illustrate the single bids modelling on a simple example.

Let us consider the example of Figure 5, of simple buy & sell bids on an economic setup -

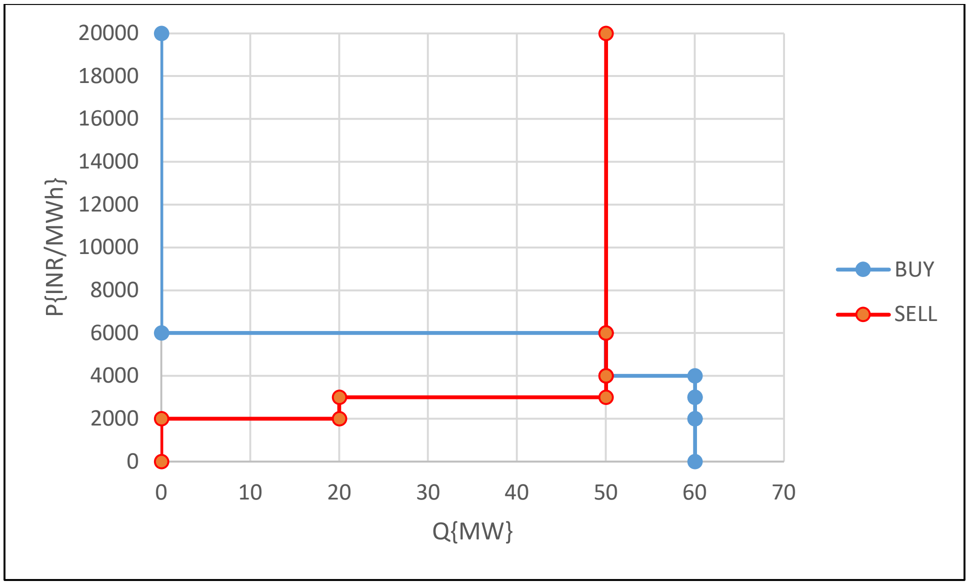


Figure 5: An example of single bid containing a curve with both negative and positive quantities.

Results for different acceptance ratios are given in Table 2.1. Note that acceptances ratio and market prices are compatible, respecting the rules described in above section.

		Point 1	Point 2	Point 3	Point 4
Buy bid 1	Quantity	10	10	0	0
	Price	0	4000	4001	20000
Sell bid 1	Quantity	0	0	-20	-20
	Price	0	2000	2001	20000
Buy bid 2	Quantity	50	50	0	0
	Price	0	6000	6001	20000
Sell bid 2	Quantity	0	0	-30	-30
	Price	0	3000	3001	20000

Table 1.1: Correspondence between acceptance ratio, accepted quantity, welfare contribution, and market price for Example 1

•Volume investigation:

•Buy bid 1 fully rejected, buy bid 2 fully accepted

•Sell bid 1 fully accepted, sell bid 2 fully accepted

•The matched volume is 50 MW

•Price investigation:

•There is a price indeterminacy requiring the price to be between 4001 and 6000 INR/MWh

•The indeterminacy is lift by means of the midpoint rule and the price of 5000.5 INR/MWh is picked.

Single bids with only supply or demand

Preliminary remark. The modelling of single bids with supply-only or demand-only within the HPX's Matching engine assumes all quantities to be positive, both for supply and demand. Quantities should be non-decreasing with the price for supply, and non-increasing with the price for demand.

Single bids (also known as interpolated curves) are simple linear orders. Each single bid defines a set of quantity-price points. At quantities falling in between two points, the price is linearly interpolated. Single bids thus define a piecewise linear price function (non-decreasing for supply orders and non-increasing for demand orders). Figure 6 shows examples of buy and sell single bids.

The single bids must fulfill the following requirement. Quantities should be non-decreasing (resp. non-increasing) with the prices for supply (resp. demand) single bids except for the first segment of the curve when it is defined at the minimum (resp. maximum) market price. In other words, horizontal segments are forbidden except at minimum market price for supply single bids and at maximum price for demand single bids.

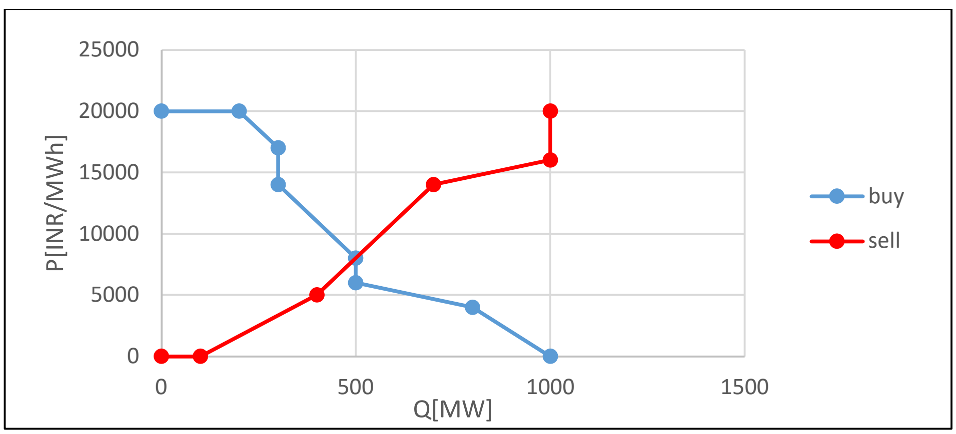


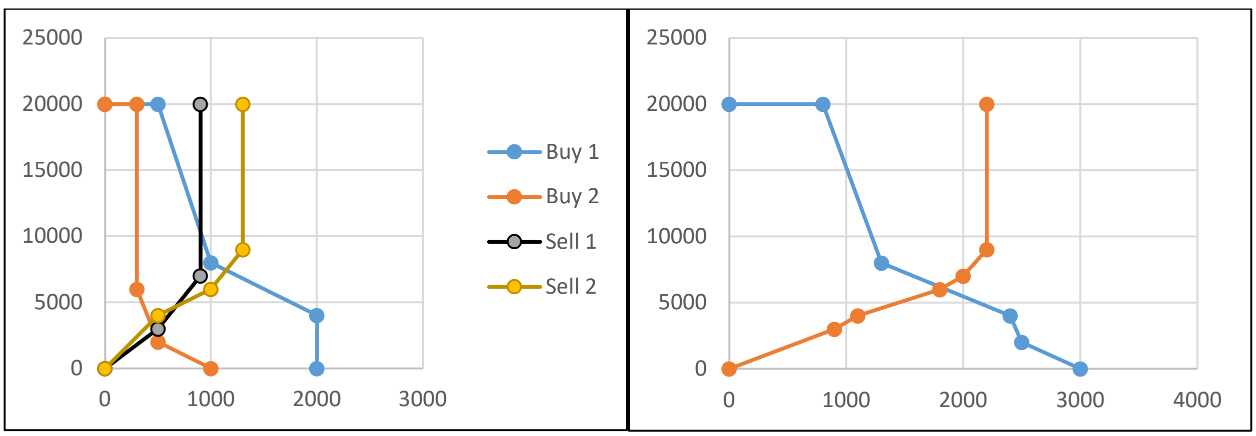
Figure 6: An example of a buy and a sell single bid. Vertical segments are allowed. Horizontal segments are allowed only at minimum market price for sell bids and at maximum price for buy bids.

Equivalence between aggregated curves crossing and welfare maximization

When there are only single bids and the network constraint are not constraining, those conditions can also be used to demonstrate that solving the welfare maximization problem is equivalent to aggregating the supply and demand curves and computing their intersection (the intersection of the two aggregated curves provides the market clearing price and cleared volume).

Let us assume we are given the single bids described by Figure 7.a. The aggregated curves are as in Figure 7.b-. Crossing the aggregated curves gives the optimal market prices of 6000 INR/MWh and the cleared volume of 1800 MW. The individual single bids are then accepted up to the quantity that they quoted at the market clearing price.

- Buy bid 1 consumes 1500MW
- Buy bid 2 consumes 300MW
- Sell bid 1 produces 1000MW
- Sell bid 2 produces 800MW



(a) Individual single bids (b) Aggregated buy and sell bids

Figure 7: Graphical representations of single bids aggregation and of the aggregated curves crossings

1.1.5. Block orders

This section introduces the block orders. Block orders offer the possibility to specify a minimum acceptance level. The order is accepted only if the accepted quantity is such that the minimum acceptance level is reached. The block orders can also span on several (consecutive or nonconsecutive) periods. The offered quantity can vary over the periods, but the minimum acceptance percentage is constant over the periods. The offered price is constant over the periods. The block orders can also be used to model minimum quantity block bids by specifying the same quantity for all the periods on which the bid is defined. Figure 8 shows two examples of block bids.

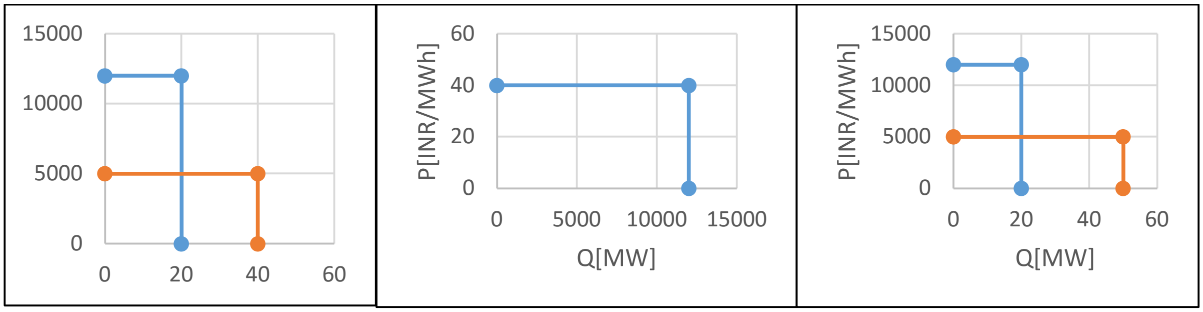


Figure 8: Two examples of block orders. Quantities defined by the blue and red bids vary over the periods. Red bid defines non-zero quantities over non-contiguous periods. The price must be the same across all periods. The filled areas under the curves represent the minimum acceptance ratios. Blue bid has a minimum acceptance ratio of 50% and red bid has a minimum acceptance ratio of 100%.

1.1.6. Mapping of HPX specific block bids

HPX uses several types of block bids: standard block bids, minimum quantity block bids, profile block bids, and linked block bids. All these block bids can be modelled by using a block order object, as described below:

1.1.7. Standard block bids

A standard block bid can be expressed as a block order with:

- a minimum acceptance ratio equal to 1: $R_o = 1$
- defined on a set T_o of consecutive periods
- and with a constant quantity $Q_O = Q_O t \forall t \in T_o$.

1.1.8. Minimum quantity block bids

A minimum quantity block bid can be expressed as a block order with:

- a minimum acceptance ratio defined as $Q_o = Q_{ot} \forall t \in T_o$ where Q_{min} is the minimum acceptance volume.
- defined on a set to of consecutive periods and
- with a constant quantity $Q_o = Q_{ot} \forall t \in T_o$.

1.1.9. Profile block bids

A profile block bid can be expressed as block order with minimum acceptance ratio $R_O = 1$. Block orders can have different quantities for different periods, allowing a modelling of profile block bids.

1.1.10. Linked block bids

Linked block bids can be used by defining parent-child links between block orders.

Example: 1 area, 2 single bids, 1 block bid

Bids Type	Qty/Price	Single bids			
		Point 1	Point 2	Point 3	Point 4
Buy bid	Quantity [MW]	20	20	0	0
	Price [INR/MWh]	0	4000	4001	20000
Sell bid	Quantity [MW]	0	0	-60	-60
	Price [INR/MWh]	0	3000	3001	20000

Bids Type	Qty/Price	Block bids
Buy bid	Quantity [MW]	20
	Price [INR/MWh]	5000

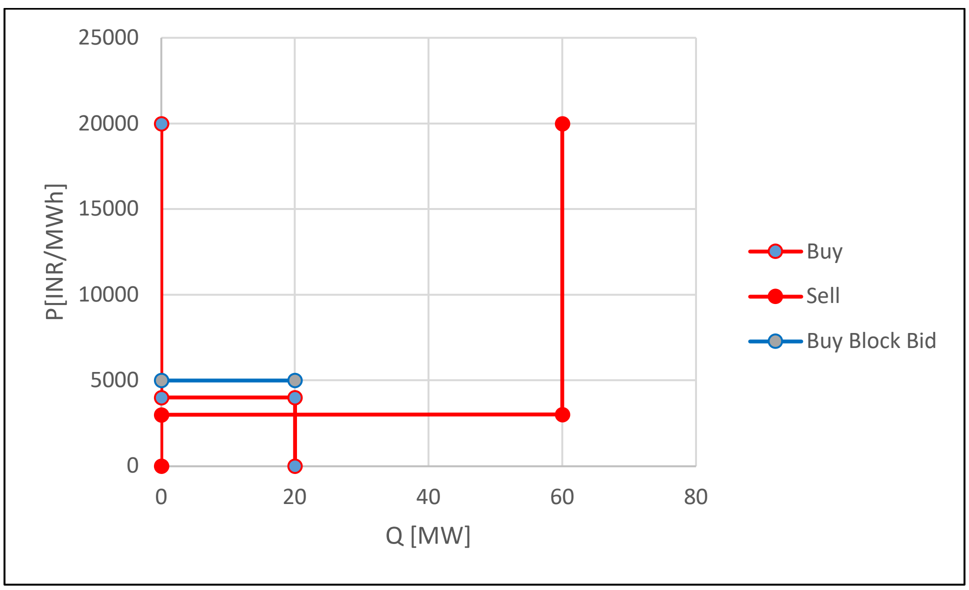


Figure: 09 Graphical view of example

•Volume investigation:

•Accepting the (buy) block bid and fully accepting the buy single bids is the best outcome as both bids are willing to offer higher price than the sell bid is asking. The matched volume is thus 40 MW.

•Price investigation:

•The algorithm then moves on to the price computation. Some sell quantity remains unmatched and sets the price (no indeterminacy): the price is 3000.66 INR/MWh (otherwise the supply bid is partially paradoxically accepted or partially paradoxically rejected).

1.1.11. Mid-Point Rule

It can happen that the acceptance criteria of the individual orders do not fully determine the market price. Such situations are referred to as vertical (price) indeterminacy as a whole interval of prices is feasible given the selection of orders. Figure 9 shows an example of vertical indeterminacy with single bids only. The aggregated curves overlap on a vertical price segment when they cross. Any price between 3000 INR/MWh and 4000 INR/MWh is feasible. The algorithm resort to the so-called mid-point rule to lift the indeterminacy on the price. This section will formalize this rule and provide an example.

1.1.12. Details of the mid-point rule

This subsection describes the different steps to compute the prices.

Prepare the midpoint rule computation. For each period $t \in T$.

1. Compute price bounds per bidding area. For each bidding area $n \in N$, determine the interval of feasible prices $\left[L_{nt}, U_{nt}\right]$ based on the quantity accepted and rejected in the single bids. Mind that this interval can be a singleton.

(a) Ln_t must be the smallest value which is

i. higher than or equal to the price of any quantity accepted in a sell single bid of area n ,

ii. higher than or equal to the price of any quantity rejected in a buy single bid of area n ,

iii. higher than or equal to the minimum market price bound (i.e., 0)

(b) Un_t must be the largest value which is

i. lower than or equal to the price of any quantity rejected in a sell single bid of area n ,

ii. lower than or equal to the price of any quantity accepted in a buy single bid of area n ,

iii. lower than or equal to the maximum market price bound (i.e., 20000)

2. Identify the regions without congestion. Group together bidding areas between which there is no congestion for this period. We thus obtain R_t disjoint sets $\left(R_{t,1}, R_{t,2}, ..., R_{t,R_t}\right)$ of bidding areas. Each of these disjoint sets is a set of bidding areas which must have the same price for period t.

(a) There is congestion on a line k if one of the shadow prices λ_{kt}^{+} or λ_{kt}^{-} of the capacity constraints on the line is non-zero.

(b) There is congestion between two bidding areas if all the paths going from the first bidding area to the second bidding area include at least one congested line.

3. Compute the price bounds per region without congestion. For each set R_t, r among the R_t disjoint sets of bidding areas obtained in point 2, compute a lower bound (L_{rt}) and an upper bound (U_{rt}) on the price as follows:

(a) The lower bound (L_{rt}) on the price is the maximum of the lower bounds on the price (L_{nt}) of the bidding areas in the set.

(b) The upper bound (U_{rt}) on the price is the minimum of the upper bounds on the price (U_{nt}) of the bidding areas in the set.

4. Compute prices by applying the midpoint rule. For each period $t \in T$ and each set $r \in R_t$ among the R_t disjoint sets of bidding areas obtained previously, we must pick a market clearing price φ_{rt} between the lower bound (L_{rt}) and the upper bound (U_{rt}). We pick the market clearing price φ_{rt} which minimizes the following expression.

$$\sum_{t \in T} \sum_{r \in R_t} \left(\phi_{rt} - \left(\frac{U_{rt} + L_{rt}}{2} \right) \right)^2$$

For each bidding area $n \in R_t$, r, the market price φ_{nt} is then set to φ_{rt}.

Observe that

• When there are no block bids, it will be feasible to bring this expression to 0 and each price φ_{rt} will be the midpoint $\left(U_{rt} + L_{rt}\right)/2$ (i.e., the midpoint of the vertical segment where the aggregated buy and sell curves of this set of bidding areas overlap).

- When there are block bids, it might not be feasible to bring this expression to 0 and the price φ_{rt} might differ from $(U_{rt}+L_{rt})/2$ as other additional constraints apply to the prices on top of the prices bounds.

Example:

Price	2000	4000
Buy Bid	200	200
Price	3000	5000
Sell Bid	200	200

In the above example of sell and buy bid,

- The sell bids acceptances imply that the market price should be between 3000 and 5000 INR/MWh.
- The buy bids acceptances imply that the market price should be between 2000 and 4000 INR/MWh.
- Consequently, the market price should be between 3000 and 4000 INR/MWh, or L_{nt} = 3000 and U_{nt} = 4000.

The midpoint rule aims to find the feasible market prices ϕ_{nt} such that the criterion

$$\left(\phi_{nt}-\left(\frac{4000+3000}{2}\right)\right)^2$$

is minimized. This amounts to minimizing the distance to the midpoint between the lower and upper bounds using a quadratic norm. The price will thus be set at 3500 INR/MWh. This minimization does not impact the welfare, nor does it change the acceptance of the orders.

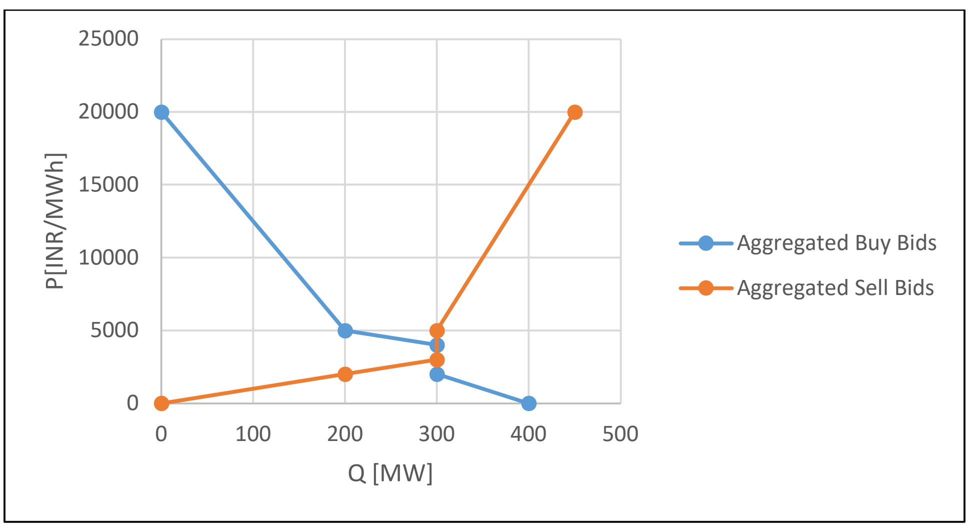


Figure 10: Graphical representation of a vertical price indeterminacy. The supply and demand curves overlap on a vertical segment. The mid-point rule lifts the price indeterminacy by setting the price to the midpoint (3500 /MWh) of the interval of feasible prices ([3000,4000]).

1.1.13. Market Splitting

Market splitting is an evolved form of implicit auctioning wherein energy component and corresponding transmission capacity between bid areas are traded simultaneously. In the market splitting methodology areas on either side of congested corridor are identified separately and initially both are cleared as if there is no interconnection between the areas, and then the area which has highest price, draws electricity from the area with the lower price just as much as the capacity of the congested line will allow. Allowing this flow into higher price area will reduce prices in the higher price bid area and would increase prices in the lower price bid area depending upon the bid prices in the respective areas.

For a simple situation involving only two areas SR and ER is illustrated as under:

In the first step, all bids from both areas are aggregated together, and a demand-supply curve is plotted as shown below –

Price (Rs. /	0	1999	2000	2999	3000	3001	3999	4000	4001	20000
ER Seller 1	0	0	-200	-200	-200	-200	-200	-200	-200	-200
ER Seller 2	0	0	0	0	-100	-100	-100	-100	-100	-100
SR Seller 1	0	0	0	0	-100	-100	-100	-100	-100	-100
SR Seller 2	0	0	0	0	0	0	0	-100	-100	-100
SR Buyer	300	300	300	300	300	300	300	300	0	0
ER Buyer	100	100	100	100	100	0	0	0	0	0
Total Buy (Mw)	400	400	400	400	400	300	300	300	0	0
Total Sell	0	0	-200	-200	-400	-400	-400	-500	-500	-500
Net (Buy-Sell)	400	400	200	200	0	-100	-100	-200	-500	-500

Result	
MCP	3000 Rs/Mwh
Volume cleared	400 MW

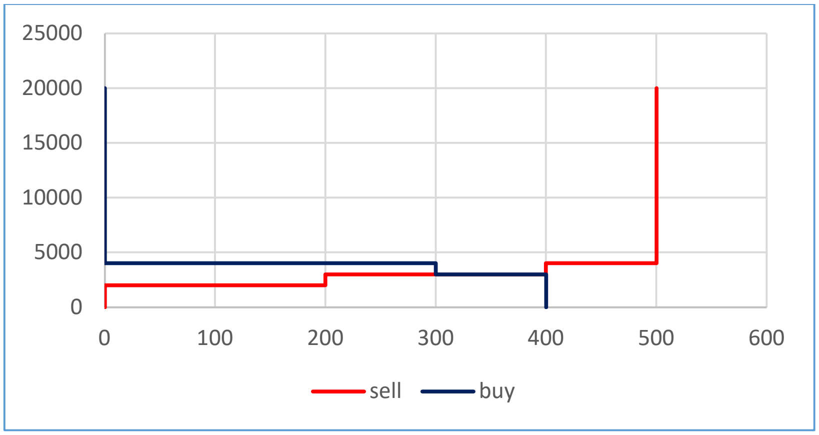
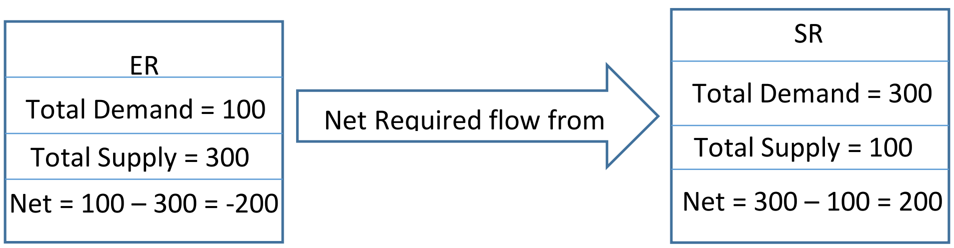


Fig 11: Demand supply curve for unconstrained solution

Case 1: As per the above-unconstrained solution, System will demand net flow from ER to SR as 200 MW from NLDC



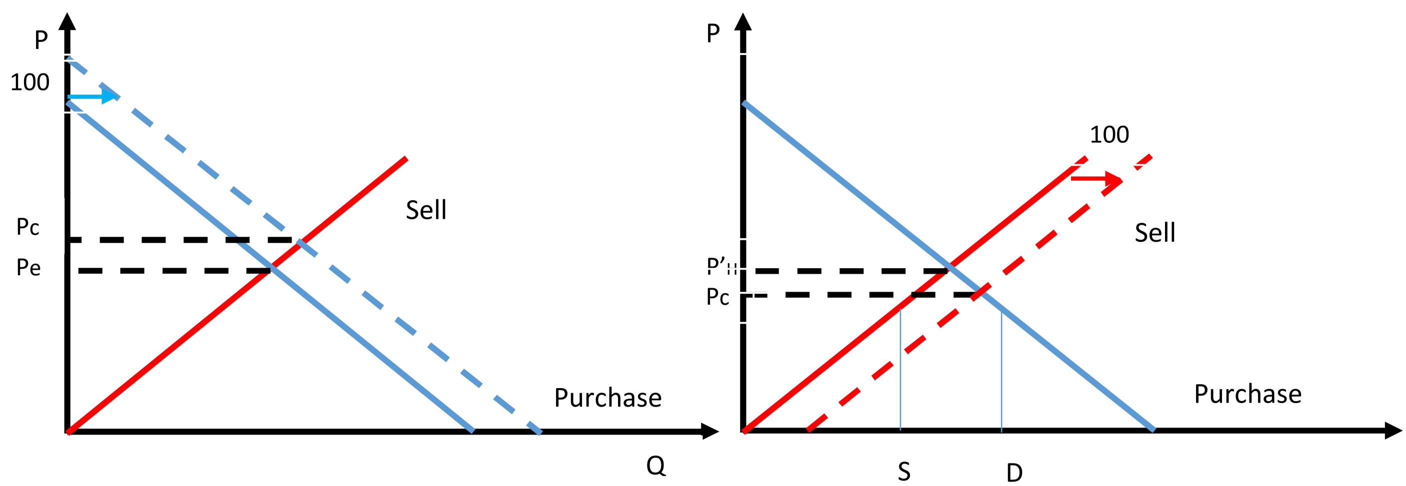
Case 2: There is congestion in ER-SR corridor and flow is constrained to 100 MW: System then splits the market in two regions i.e., deficit (SR) and surplus region (ER) and re-run the calculation for both the regions separately considering the flow constraint and then derive the ACP and ACV. It means system brings the net sell/buy in ER region as 100 on surplus side (Outflow from ER) and accordingly at that point the prices discovered will be ACP of ER. Similarly, system brings the net sell/buy in SR as 100 on deficit (Inflow) side and accordingly at that point the prices discovered will be ACP of SR.

	Price (Rs. /MWh)	**0**	**1999**	**2000**	**2999**	**3000**	**3001**	**3999**	**4000**	**4001**	**20000**
ER Surplus Region	**ER Seller 1**	0	0	-200	-200	-200	-200	-200	-200	-200	-200
	ER Seller 2	**0**	**0**	0	0	**-100**	**-100**	**0**	**-100**	**-100**	**-100**
	ER Buyer	100	100	100	100	100	0	100	0	0	0
	Net (Buy-Sell)	**100**	**100**	-100	-100	**-200**	**-300**	**-300**	**-300**	**-300**	**-300**

	Price (Rs. /MWh)	**0**	**1999**	**2000**	**2999**	**3000**	**3001**	**3999**	**4000**	**4001**	**20000**
SR Deficit Region	**SR Seller 1**	0	0	0	0	-100	-100	-100	-100	-100	-100
	SR Seller 2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-100**	**-100**	**-100**
	SR Buyer	300	300	300	300	300	300	300	300	0	0

	Net (Buy-Sell)	300	300	300	300	200	200	200	100	-200	-200

Result	**ACP (Rs. /MWh)**	ACV sale (MW)	ACV (Buy)
ER	2499.5	200	100
SR	4000	200	300
Total		400	400



The main objective of the concept is fulfilled:

- All grid constraints are relieved
- The available capacities are fully utilized
- The sale-purchase balance requirement is satisfied in both areas (at different price levels)

1.1.14. Primal indeterminacies

Volume indeterminacies:

The first type of indeterminacies is linked to the cleared volume. It happens when a buyer and a seller are both willing to buy/sell at the same price and that no constraint prevents them to be matched together. In terms of welfare, it is equivalent to match them or not leading to the indeterminacy.

To lift such indeterminacy, HPX aims at maximizing the total matched volume. This maximization is necessary in the presence of block bids with a minimum acceptance ratio different than 1 as well as when the market clearing price is at the maximum or minimum market price.

For example, let us consider a simple single period market with 3 block orders as follows.

- Block 1: 2 MW of supply at 0 INR/MWh with a minimum acceptance ratio of 0.75
- Block 2: 1 MW of demand at 0 INR/MWh with a minimum acceptance ratio of 0.5
- Block 3: 1 MW of demand at 10 INR/MWh with a minimum acceptance ratio of 0.5

To maximize the welfare, the block 3 must be fully accepted with the block 1 as counterparty. To satisfy the minimum acceptance ratio of the block 1, the block 2 must also be accepted. Any solution that accepts between 1.5 MW and 2 MW the block 1, between 0.5 MW and 1 MW the block 2 and at 1 MW the block 3 is welfare optimal. The volume maximization problem ensure that the solution matching 2 MW is picked.

HPX also aims at harmonizing the acceptance ratios of the single bids when the market is cleared at the minimum or maximum market price. When this happens, the total quantity matched in the single bids at the minimum or maximum market price is distributed to the single bids following a pro-rata rule.

For example, let us consider a simple single period market with 3 single bids as follows.

- Single bid 1: 70 MW of supply at 0 INR/MWh
- Single bid 2: 30 MW of supply at 0 INR/MWh
- Single bid 3: 90 MW of demand at 20000 INR/MWh

The total volume is 90 MW with 63 MW produced by single bid 1 and 27 MW produced by single bid 2 (they have the same acceptance ratio: 0.9).

Tie-breaking for block bids

Two block bids are considered identical-but-price when

- There is no congestion between their respective bidding areas,
- They are both supply or demand orders,
- They are defined on the same periods and offer the same quantity on each period,
- They are not involved in links (no parent nor child block).

It can be that only one of two identical-but-price block bids can be selected in the final solution (e.g., if not enough quantity is available to match them both). If so, identical-but-price block bids are selected by increasing prices for supply bids and decreasing prices for demand bids.

Two block bids are considered identical if they are identical-but-price and have the same price. Again, it can be that only one of two identical block bids can be selected in the final solution. Identical block bids are selected by increasing timestamp (smallest timestamp first).

It can be that the priority criterion described in this section doesn't seem to be satisfied. For example, the final solution could accept a block bid while another identical-but-price block bid is rejected (there is thus no congestion between their respective bidding areas). It means that swapping the acceptances of the two bids is infeasible and would lead to the violation of some network constraint.

1.2. Continuous Matching Algorithm

In this type of matching, buy and sell bids are placed during the trading period. The buyers and sellers get matched on continuous basis on a price-time priority. In case of more than one order having the same price, the order with the earlier time will get the priority in matching. If trade is not executed, then both the bids shall be visible in the market without the name of the client. Trader can see the name of its own client but not of the counterparty Buyer and seller does not know all the counterparties while placing bids, but they can check best five buyer and seller bids in market watch screen. Buyer with maximum price quote and seller with minimum price quote are considered as best buyer and best seller respectively.

Following are the order matching rules:

1.2.5. As soon as order enters the system after validation, it is checked if it can be matched.

Orders are matched on price & time priority.

1.2.6. Best buy and sell orders are matched, best buy order is one with the highest bid price and

best sell price is the one with lowest price.

1.2.7. An order may match partially with another order resulting in multiple trades

1.2.8. List of orders available in the Continuous Trade Session.

I. Rest of day (Day): The order will be valid till the end of trading day.

II. Immediate or Cancel (IOC): The order placed will match or cancel immediately, orders will not be in pending status.

III. End of Session (EOS): Valid for auction session only

IV. Fill or Kill (FoK**):** This order will match the whole order OR delete the whole order**.**

1.2.9. Example on Continuous matching Algorithm:

Let's assume the following buy and sell bids are available in the system, the best buy bid is offered by the buyer B1 i.e., 400 MW at Rs. 4300/MWh and best sell bid is placed by seller S1 i.e., 300 MW at Rs 4500/MWh. Since the price of best buy bid and best sell bid is not matching, the orders will not get matched and show pending in the system.

Orders					
Buyer	Buy Price (Rs/MWh)	Buy qty (MW)	Seller	Sell Price (Rs/MWh)	Sell qty (MW)
B1	4300	400	S1	4500	300
B2	4200	500	S2	5000	400
B3	4000	600	S3	5200	600
B4	3800	300	S4	5400	500
B5	3500	400			

In the above example, let's assume a new Seller S5 place a sell bid for 600 MW at Rs. 4200/MWh. As the price quoted by seller S5 will match with the price quoted by buyer B1 & B2 the transaction will take place between seller S5 and buyer B1 and seller S5 and buyer B2 as illustrated in the Table given below.

Orders						Trades			Pending order					
Buyer	Buy Price	Buy qty	Seller	Sell Price	Sell qty	Transactions	Trade Price	Trade Qty	Buyer	Buy Price	Buy qty	Seller	Sell Price	Sell Qty
B1	4300	400	S5	4200	600	B1 – S5	4300	400	B2	4200	300	S1	4500	300
B2	4200	500	S1	4500	300	B2 – S5	4200	200	B3	4000	600	S2	5000	400
B3	4000	600	S2	5000	400				B4	3800	300	S3	5200	600
B4	3800	300	S3	5200	600				B5	3500	400	S4	5400	500
B5	3500	400	S4	5400	500									

1.3. Double-sided close bid uniform price step auction Algorithm for Term Ahead Market/Green Term Ahead Marker, Renewable Energy Certificates & ESCerts

If the auction is having prices (buy price >= Sell Price) in the order book, then matching of the auction take place. The equilibrium price is determined with following conditions

1. Maximum tradable volume: The Equilibrium Price is the price at which maximum volume in the market can be traded.
2. Minimum unbalance: If there are multiple prices having maximum tradable volume, the price that leaves the least volume untraded at its level is chosen as Equilibrium Price.

Auction uniform price discovery is guided through four principles, which test different condition, and in any principle during matching process, system justifies the price than that became the auction uniform price and system will not check further.

The Auction Uniform Price calculation logic is explained below with the help of an example.

The Order Book would be sorted on Best Buy and Best Sell basis for a product at the end of the Auction session as below:

BUY			SELL		
Order	Quantity	Price	Price	Quantity	Order
1	1350	2030	2050	87	10
2	8460	2024	2045	3426	11
3	570	2022	2038	6495	12
4	14910	2020	2030	2550	13
5	2400	2019	2023	570	14
6	4920	2015	2020	5250	15
7	1620	2013	2019	1080	16
8	270	2010	2015	3480	17
9	1373	2008			

1) Principle: Determining the Maximum Tradable Volume

The principle would establish the price(s) at which maximum tradable volume would be executed. There would be two steps involved in applying this principle.

a. STEP 1 – Determine the Cumulative Buy and Sell quantities at each eligible price. The Cumulative Buy and Sell quantities at each price are as follows:

BUY		PRICE	SELL	
Cumulative buy Quantity	Buy quantity At price		Sell quantity at price	Cumulative Sell quantity
0	0	2050	87	22938
0	0	2045	3426	22851
0	0	2038	6495	19425
1350	1350	2030	2550	12930
9810	8460	2024	0	10380
9810	0	2023	570	10380
10380	570	2022	0	9810
25290	14910	2020	5250	9810
27690	2400	2019	1080	4560
32610	4920	2015	3480	3480
34230	1620	2013	0	0
34500	270	2010	0	0
35873	1373	2008	0	0

b. STEP 2 – Establish the total tradable volume at each eligible price (i.e., Maximum Quantity which may be traded at that each price). The total tradable volume at a price would be computed as 'Minimum of Cumulative Buy and Cumulative Sell quantity' at the respective price. The Maximum Executable Volume (MEV) for each eligible price is as below:

BUY		PRICE	SELL		Maximum Executable volume
Cumulative buy Quantity	Buy quantity At price		Sell quantity at price	Cumulative Sell quantity	
0	0	2050	87	22938	0
0	0	2045	3426	22851	0
0	0	2038	6495	19425	0
1350	1350	2030	2550	12930	1350
9810	8460	2024	0	10380	9810
9810	0	2023	570	10380	9810
10380	570	2022	0	9810	9810
25290	14910	2020	5250	9810	9810
27690	2400	2019	1080	4560	4560
32610	4920	2015	3480	3480	3480
34230	1620	2013	0	0	0
34500	270	2010	0	0	0
35873	1373	2008	0	0	0

Note: The Maximum Tradable Volume is the highest value amongst 'Maximum Tradable Volume' derived for all price points.

In this example, Tradable quantity may be 9,810 at prices 2024, 2023, 2022 and 2020. Therefore, as per Principle 1, the algorithm would eliminate all other price points as the potential Auction Uniform Price. To narrow down the price choices, system establish the minimum unbalance.

2) Principle: Establishing the Minimum Unbalance:

The second principle would figure out the eligible price levels (from prices 2024, 2023, 2022 and 2020) at which the Unmatched Quantity is a minimum. The Minimum Unbalance at each price level is equal to 'Cumulative Buy Quantity – Cumulative Sell Quantity'

BUY		PRICE	SELL		Maximum Executable volume	Minimum unbalance (Cumulative buy qty-cumulative sell qty)
Cumulative buy Quantity	Buy quantity At price		Sell quantity at price	Cumulative Sell quantity		
9810	8460	2024	0	10380	9810	570
9810	0	2023	570	10380	9810	570
10380	570	2022	0	9810	9810	-570
25290	14910	2020	5250	9810	9810	15480

Note: *0 is the lowest Minimum Unbalance Quantity.*

The minimum Unbalance occurs at prices 2024, 2023, 2022. Therefore, as per completion of Principle 2, the Prices eligible for Auction Uniform Price Calculation are 2024, 2023, 2022. In the above process price 2020 is eliminated and for further refining the auction prices, 3rd principle will be applied for the market pressure

3) Principle: Ascertaining where the Market Pressure exists:

3 rd. principle will check where the Market pressure exist on buy side or on sell side Following conditions will be checked and accordingly market uniform auction price will be determined:

a. If minimum unbalance for all the price point established in 2nd principle is –ve then minimum of the price will be the uniform auction price

b. If minimum unbalance for all the price point established in 2nd principle is +ve then maximum of the price will be the uniform auction price.

If the minimum unbalance having +ve and –ve values, then all the price point will be further refined through 4th principle. In the abovementioned example we are having both +ve and –ve minimum unbalance as shown below:

BUY		PRICE	SELL		Maximum Executable volume	Minimum unbalance (Cumulative buy qty-cumulative sell qty)
Cumulative buy Quantity	Buy quantity At price		Sell quantity at price	Cumulative Sell quantity		
9810	8460	2024	0	10380	9810	570
9810	0	2023	570	10380	9810	570
10380	570	2022	0	9810	9810	-570

All the prices i.e., 2024, 2023 and 2022 are still valid therefore 4th principle will be checked and accordingly a uniform price auction will be determined.

4) Principle: Marking of sign change and Average of Price Points:

The fourth and final principle determines Auction Uniform Price from the range of prices established in Principle 3 (from prices 2024, 2023, 2024).

a. There are two steps to this Principle. The first step is to narrow the options of potential Auction Uniform Prices within the derived price range.

Step 1

BUY		PRICE	SELL		Maximum Executable volume	Minimum unbalance (Cumulative buy qty-cumulative sell qty)
Cumulative buy Quantity	Buy quantity At price		Sell quantity at price	Cumulative Sell quantity		
9810	0	2023	570	10380	9810	570
10380	570	2022	0	9810	9810	-570

b. STEP 2 The auction uniform price would be the average of the price where the minimum unbalance changes its sign i.e., Average (2022, 2023) = 2022.5

The discovered Auction Uniform Price would be ‘2022.5’

Note 1: If discovered Auction Uniform Price is not as per Product’s Price Tick then Auction Uniform Price would be rounded off to the nearest product’s price tick.

All the matching orders would get traded at the Determined Auction Uniform Price, regardless of the price actually stated when placing an order. The Order Priority for matching purpose would be determined on Price time priority basis. All the Auction Session’s Unmatched Pending Orders would get cancelled.

Note 2: If the Auction session has no overlapping Buy and Sell orders (i.e., Trades = 0), then the above-mentioned conditional rule to determine ‘Auction Uniform Price’ would not be referred.

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