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FRA algorithm - Public description

11.02.2022
Paris
Ref.1.0

Table of Contents

Glossary

Products	Capacity reservation of frequency products for balancing on the frequency response auction. For example, Dynamic Containment Low (DCL), Dynamic Containment High (DCH).
Auction	Mechanism to match buy and sell orders of different product types on different periods and output clearing prices and executed quantities.
FRA	Frequency Response Auction
Market clearing price (or clearing price or market price)	There is one market clearing price per product, per period. The market clearing price must be compatible with the acceptance/rejection statuses of the orders.
EFA block	Electricity forward agreement, other name for one the delivery periods spanned by the auction. Currently, an EFA block consists out of 4 hours. Note: EFA blocks are not to be confused with block orders
Step Linear Orders	Step linear orders are a set of orders for which the willingness to be paid (or to pay) is defined by a single price, volume is submitted on one period, accepted volume can be any value between 0 and the submitted volume. This set can be aggregated in a monotonous curve while ranking the orders by decreasing prices (for buy orders) or by increasing prices (for sell orders). For FRA auctions, only step linear buy orders are implemented.
Block orders	Block orders are a set of orders for which the willingness to be paid (or to pay) is defined by a single price and a volume per EFA block the order is submitted on.
Parent Block	A Parent Block is named 'C01'; the execution of a C01 block order does not depend on the execution of another block order.
Child Block	A Child Block is named 'C02'; the execution of a C02 block order depends on the execution of all its parent block orders.
Order Surplus	For step linear orders and block orders, the surplus of a sell (resp. buy) order is defined as the difference between the market clearing price (resp. order price) and the order price (resp. market clearing price) times the accepted volume of the order. A positive surplus means that the sell (resp. buy) order is accepted above (resp. below) what the actor is willing to receive (resp. willing to pay). Note 1: for multi-period block orders, the surplus is the sum of surpluses on each period. Note 2: this definition can be extended to rejected orders, in that case, it is computed based on the submitted volume instead of the accepted volume and we speak of theoretical order surplus.
Market welfare (or market value Or market surplus)	The sum of the order surpluses of all the accepted orders.

Paradoxically Accepted Orders	A sell (resp. buy) order is deemed paradoxically accepted if its surplus is negative. It means that this order is accepted below (resp. above) what the actor is willing to receive (resp. willing to pay).
Paradoxically Rejected Orders	A sell (resp. buy) order is deemed paradoxically rejected if its theoretical surplus is positive. It means that this block is rejected above (resp. below) what the actor is willing to receive (resp. willing to pay).
Demand Orders (linear curves orders, demand linear orders)	The demand curve is a Step Linear Order (see definition above) used in FRA context by NGESO to reflect its buy orders.
Offer Orders (block orders, Supply block orders)	In FRA context, offer orders are Sell block orders submitted by market participants (frequency response products suppliers)
Minimum Acceptance Ratio (MAR)	Minimum share of an order that must be executed if the order is not fully rejected. As an example, a MAR of 0.3 (or 30%) means that at least 30% of an order must be executed or the order is fully rejected.
Actual Acceptance Ratio (AAR)	Share of an order that has been executed (unrounded value between the MAR and 1) or 0 if the order has been rejected.
Curtailable Block Orders (& Fully curtailable block offers)	Curtailable block orders are block orders which minimum acceptance ratio (see definition above) is lower than 1. A fully curtailable block order / offer has a MAR of 0.
Non-curtailable block orders	Non-Curtailable block orders are block orders which minimum acceptance ratio (see definition above) is 1.
Linked Block Orders	Linked block orders are block orders whose execution conditions or is conditioned by the execution of another block order
Loop block orders	Loop block orders are a pair of linked block orders where each block conditions the execution of the other.

Introduction

HELENA is the clearing engine or algorithm - to calculate Frequency Response Auction (FRA) results.

The Frequency Response Auction is organized by product type, i.e. same product type orders are matched together and HELENA implements a process for matching together same product type orders.

HELENA collects demand and offer orders of each product type as inputs and outputs clearing prices of each product type and each period, the set of executed orders and their executed volumes.

The set of FRA business rules which indicate the restrictions on the input - what are the allowed orders - and the properties that the output must satisfy - how are orders executed and how is the execution/rejection of orders reflected into the clearing prices - is denoted the market design.

Clearing FRA is achieved by solving an optimization problem, where the main objective is the maximization of market welfare and constraints are given by the business rules of the market design.

Technically speaking, HELENA is developed in JAVA and invokes XPRESS as an optimization solver.

Section 1 describes FRA's market design.

Section 2 describes how HELENA is configured to implement FRA's clearing.

Annexes provide several graphical illustration of the concepts introduced in the main sections.

1. Market design of Frequency Response Auction

1.1 Welfare maximization

The objective of the auction is to determine the accepted volumes of orders that maximizes the market welfare, that is to say the total surplus generated by matching the orders, across all products and delivery periods defined for that auction.

See example in Annex 3.

1.2 Supply-Demand balance

For each product and delivery period, the auction must be balanced, that is to say the sum of executed volumes of supply orders must match the sum of executed volumes of demand orders.

1.3 Buy orders: Demand linear orders

In FRA, demand linear orders are stepwise buy orders (and National Grid ESO is the only buyer). Orders of same product type are aggregated into a stepwise curve decreasing with prices (two consecutive points always have either the same price or the same volume).

1.3.1 Clearing properties of demand linear orders

The main rule is that linear orders cannot be paradoxically accepted, that is to say, executed while generating a negative surplus.

More specifically with respect to prices, clearing of linear demand orders satisfies the following rules:

- A linear demand order is rejected when the Market Clearing Price is higher than the demand order price. In this situation, the linear demand order remains unmet;
- A linear demand order can be executed - fully or partially - when the Market Clearing Price is lower than the demand order price;
- A linear demand order can be rejected even if the Market Clearing Price is lower than the demand order price in case there is no supply left at this price to meet the demand order; and
- A linear demand order is not executed for a volume more than the volume limit specified in the order.

See examples in Annex 5.

1.4 Sell orders: Supply block orders

In FRA, sell orders are block orders. In general, a block order is defined by:

- A product type;
- A price limit;

- A set of periods;
- A volume profile: one volume per period, volume can be different for every period;
- A minimum acceptance ratio (MAR): the order is either rejected or accepted at any rate above its MAR; and
- (optional) link to parent block (C01).

1.4.1 Clearing properties of (general) block orders

The main rules are that:

- If the block order is submitted on several consecutive periods, the actual acceptance ratio - executed volume divided by submitted volume - is the same on all periods; and
- Block orders cannot be paradoxically accepted, that is to say executed while generating a negative surplus.

More specifically related to prices, the clearing of block orders satisfies the following rules:

- if the block order is *in-the-money*[1], then the block order can be one of:
  - fully rejected (Paradoxically Rejected Blocks[2]); or
  - (entirely or partially) accepted.

- if the block order is *at-the-money*[3], then the block order can be one of:
  - fully rejected; or
  - (entirely or partially) accepted.

- if the block order is *out-of-the-money*[4], then the block order must be entirely rejected (there are no Paradoxically Accepted Blocks). This statement especially holds for blocks that are not part of a block family.

Additional rules apply to specific kinds of block orders as described in the subsequent sections.

1.4.2 Curtailable block orders

A block order is said to be curtailable or not depending on its MAR value:

- Non-curtailable block orders (MAR=1)
  These block orders are neither partially nor paradoxically executed. Therefore, they can only be either executed fully, or fully rejected. Because of this constraint this is called a "fill or kill constraint".

[1] : an offer block order is said in-the-money when the average of the rounded Market Clearing Prices over the relevant periods and weighted by the corresponding executed volume is higher than the price limit of the order

[2] Paradoxically Rejected Blocks (PRB): Because of the block order execution constraints, some offer block orders can be rejected even if their price limit is below the market clearing price, in which case they are called PRB.

[3] : an offer block order is said at-the-money when average of the rounded Market Clearing Prices over the relevant periods and weighted by the corresponding executed volume is equal to the price limit of the order

[4]: an offer block order is said out-of-the-money when average of the rounded Market Clearing Prices over the relevant periods and weighted by the corresponding executed volume is smaller than the price limit of the order

- Curtailable block orders (MAR<1)
  These block orders can be partially executed as long as their acceptance ratio are greater than their MAR values. If a block is partially executed, it is *at-the-money* (its submission price is equal the market clearing cleared price). Fully-curtailable block orders are a sub-case of curtailable block orders where MAR=0

1.4.3 Linked block orders - linked family

Block orders can be linked together, i.e. the acceptance of individual block orders can be made dependent on the acceptance of other block orders. The block which acceptance depends on the acceptance of another block is called “child block”, whereas the block which conditions the acceptance of other blocks is called “parent block”. The block orders (parent C01 and child(ren) C02) linked together are called linked family.

In FRA context, linked families have a specific pattern:

- There is only one parent per family
- Parent block orders are non-curtailable orders, either single-period or multi-period block
- Child block orders are fully curtailable single-period block orders
- Parent and child(ren) have the same product type and are linked to the same portfolio / unit.
- A parent can have at most one child per period. The child(ren) can be defined
  - on one of the period of its parent; and/or
  - on the period immediately before the first period of its parent; and/or
  - on the period immediately after the last period of its parent.

An illustration showing the interaction between parent and child(ren) block orders can be seen in the Annex 4.2.

The main clearing rules are that:

A child cannot be accepted if the parent isn’t accepted

The clearing of linked family satisfies the following rules:

- A child block which is out-of-the-money cannot be accepted (see example 1 in annex 6);
- A child block cannot be accepted in case its parent is rejected (see example 2 in annex 6); and
- A parent block which is out-of-the-money can be accepted in case its child blocks provide sufficient surplus to at least compensate the loss of the parent. (see example 3 in annex 6). When executed, the surplus of a family is non-negative.

1.4.4 Loop block orders

Loop blocks are an extension of linked block orders: it is a 2-block linked family where the two block orders are parent of each other. Unlike “regular” linked families, the 2 block orders can be of different product types.

Here are their characteristics in FRA:

- Can span more than one period;
- Can be curtailable (or not) with minimum acceptance ratio (MAR) in [0;1]; and
- Can be of different product types.

The clearing of loop block orders satisfies the following rules:

- If accepted, the surplus of the loop family must be non-negative; and
- The two block orders have the same acceptance ratio.

See example in Annex 7.

1.5 Indeterminacies

1.5.1 Price minimization

There are cases where multiple solutions of the Frequency Response Auction Problem have identical executed volumes and identical welfares but different values for the clearing prices are possible. These cases are called price indeterminacies.

In such cases, HELENA will pick up the price which is as close as possible to the price floor (minimum price of the auction) and while still satisfying all the other clearing properties.

1.5.2 Volume indeterminacies rules

There are cases where multiple solutions of the Frequency Response Auction Problem have identical prices, and identical welfares but different volumes sold or bought on some period/product. The cases are called volume indeterminacies.

Currently, there is no rule to choose among the different solutions.

The solution returning by the solver is not random but “chosen” by the solver depending on its own solution path. In other words this solution is reproducible / deterministic (if we run “n” times the algorithm in the same conditions, the solution will always be the same)

2. Auction implementation

2.1 Traded products

Products cleared in FRA are configurable in HELENA.

Currently, the following products are configured in FRA Daily Auction:

- DCH: Dynamic Containment High
- DCL: Dynamic Containment Low
- DMH: Dynamic Moderation High
- DML: Dynamic Moderation Low
- DRH: Dynamic Regulation High
- DRL: Dynamic Regulation Low

2.2 Time horizon

The number of delivery periods and their lengths considered in FRA are configurable in HELENA. Currently, the daily FRA is configured with 6 periods - also denoted EFA blocks - of four[5] (4) hours.

2.3 Computational time

The time allowed to HELENA to compute results is configurable. Currently it is set to 5 minutes.

Since the launch of FRA in 2019, including the weekly auction trial period, the total computational time has not exceed 5 seconds.

2.4 Precision and rounding

During its computations, HELENA handles unrounded values in order to provide results which satisfy all constraints with a target tolerance or, at worst, with a worst-case tolerance of 10^{-5} (and in any case 10^{-3}). Those unrounded values for prices and executed volumes are rounded before being published. Tolerances and rounding can be configured.

For instance, for FRA market:

- Targe tolerance is 10^{-5}
- Worst-case tolerance is 10^{-3}
- Prices are rounded with two digits (e.g. £0.01 MW/h)
- Executed volumes are rounded with zero digits (e.g. 1MW)

2.5 Price boundaries

Published prices must be within predefined boundaries. HELENA is designed to support to support different boundaries per product.

[5] three (respectively five) on short (respectively long) clock change day.

Currently, HELENA is configured so that prices are in [£0 /MW/h, £999.99 /MW/h].

2.6 Optimality and quality of the solution

During its execution, HELENA will typically generate several feasible solutions - solutions that satisfy the clearing rules of the market design. The best solution in terms of welfare is selected among these solutions at termination of the algorithm. That solution is the best possible solution - the optimal one - if HELENA had the time to find it, otherwise, if limited by the time limit, the solution returned is best solution among the feasible ones that were found.

2.7 Fairness

HELENA is a transparent implementation of the FRA market design.

In the FRA market design nor its HELENA implementation, buy side is not favored above sell side nor sell side over buy side, nor sellers over each other.

Orders are only executed based on their contribution to the market welfare if they satisfy the clearing properties.

3. Annex: Market welfare examples

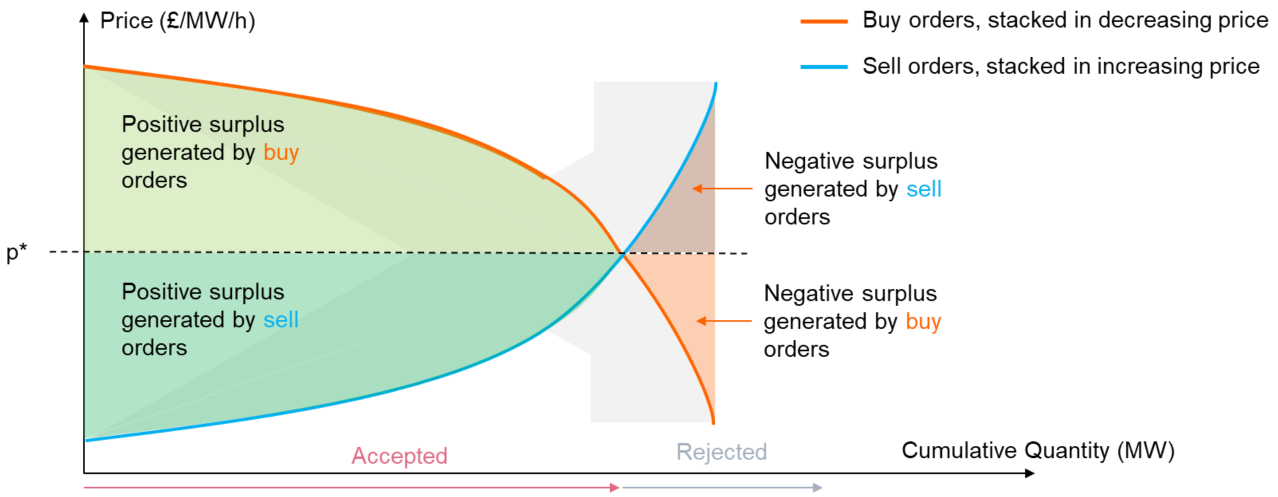


Figure 1 Market welfare - general case

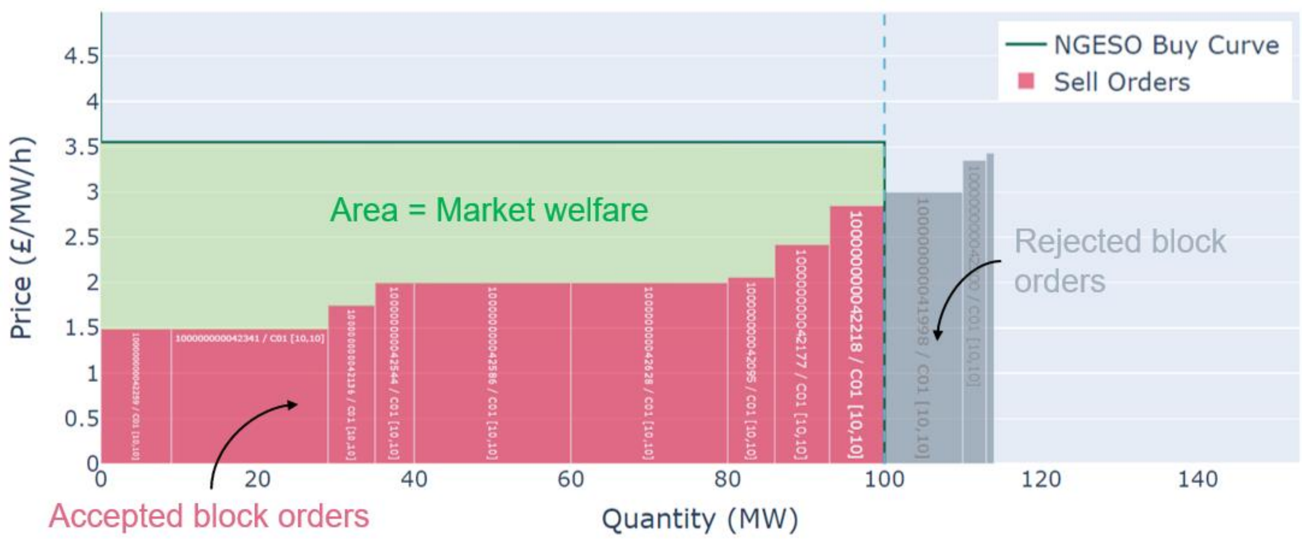


Figure 2 Market welfare - FRA LFS, auction 2020-08-14 EFA period 10

4. Annex: Block order examples

4.1 Multi-period block order

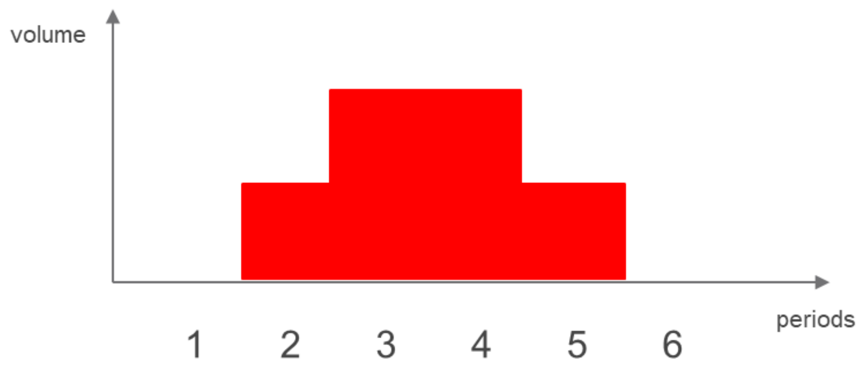


Figure 3 The multi-period block order spans over 4 periods, with possibly different volumes at each period

4.2 Multi-period linked family

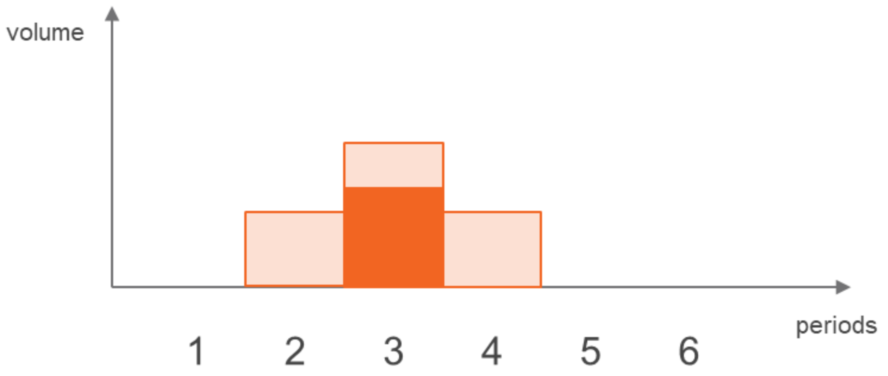


Figure 4 Family with a single-period, non-curtailable parent block linked with 3 single-period, fully curtailable child blocks

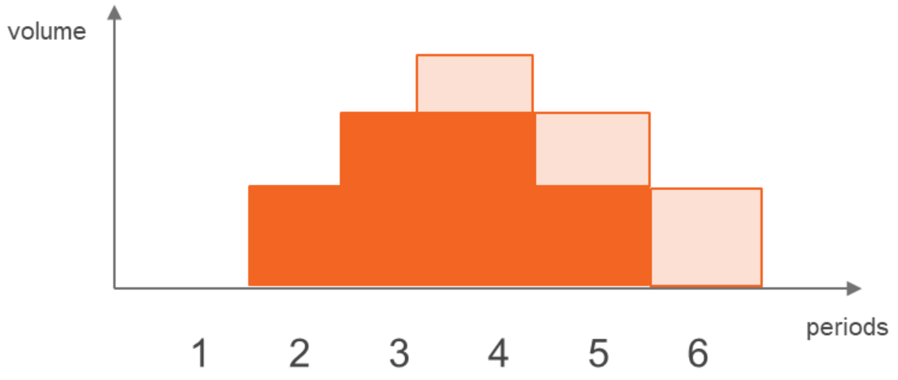


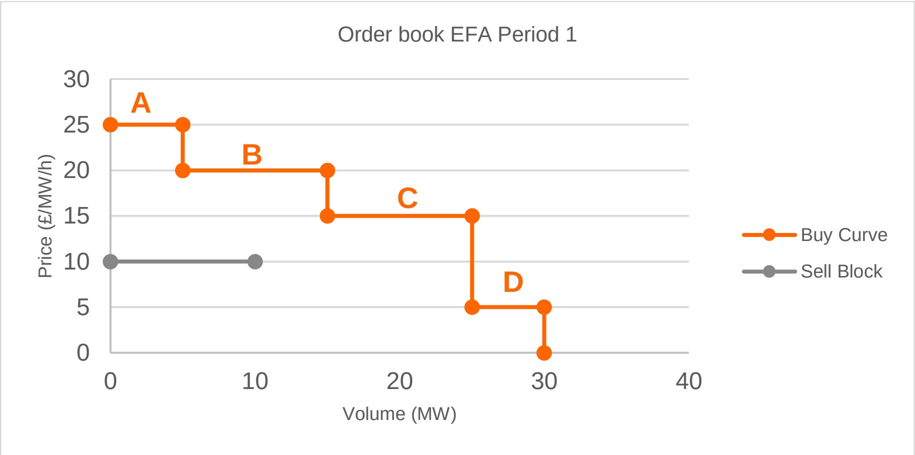
Figure 5 Family with a multi-period, non-curtailable parent block linked with 3 single-period, fully curtailable child blocks

5. Annex: Linear buy orders clearing conditions

The clearing of linear demand orders satisfies the following rules:

1. A linear demand order is rejected when the Market Clearing Price is higher than the demand order price. In this situation, the linear demand order remains unmet.
2. A linear demand order can be executed - fully or partially - when the Market Clearing Price is lower than the demand order price.
3. A linear demand order can be rejected even if the Market Clearing Price is lower than the demand order price in case there is no supply left at this price to meet the demand order.
4. A linear demand order is not executed for a volume above the volume limit specified in the order.

The following graph illustrates those rules:



In this situation, the market clearing price is set at £10 /MW/h which is the price of the sell block order.

Buy order A is fully executed and its price is greater than clearing price. It corresponds to rule 2. Similarly, buy order B is partially executed and its price is greater than the clearing price. It also corresponds to rule 2.

Buy order C is rejected although its price is greater than the clearing price. It corresponds to rule 3. Buy order D is rejected and its price is lower than the clearing price. It corresponds to rule 1. 5 MW of buy order A are executed given a volume limit of 5 MW. It corresponds to rule 4.

Similarly, 5 MW of buy order B are executed given a volume limit of 10 MW. It also corresponds to rule 4.

Orders C and D with unmet volumes are also compliant with rule 4.

6. Annex: Linked family clearing conditions

In the following examples, we will assume the following (simplistic) set-up:

- 2 EFA periods of four hours each
- 1 sell parent block of 10 MW submitted at £10 /MW/h on EFA period 1
- 1 sell child block of 10 MW submitted at £20 /MW/h on EFA period 2

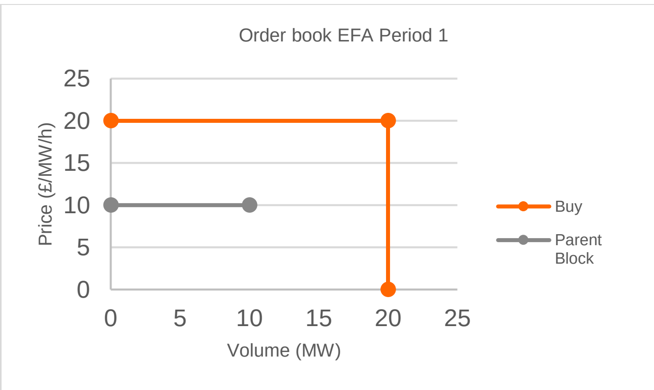
1. A child block which is out-of-the-money cannot be accepted

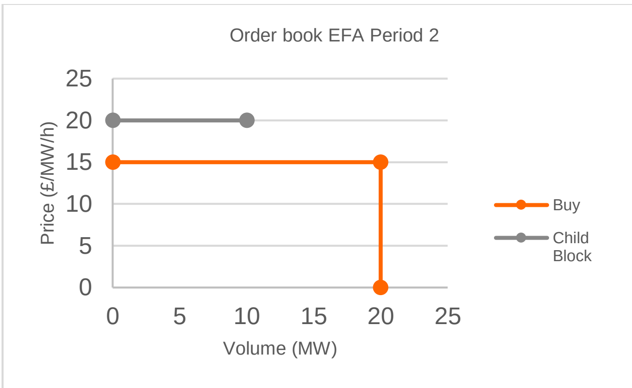
In this example, we will assume that there is:

- One buy order of 20 MW submitted at £20 /MW/h on EFA period 1
- One buy order of 20 MW submitted at £15 /MW/h on EFA period 2

The parent order is accepted.

If the child order were accepted, the family could still generate a non-negative surplus but the child order cannot be accepted because it is out-of-the-money (price cannot be set above £15 /MW/h on period 2).



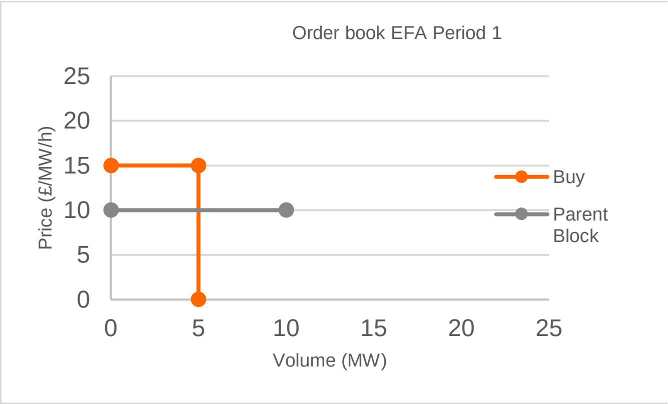


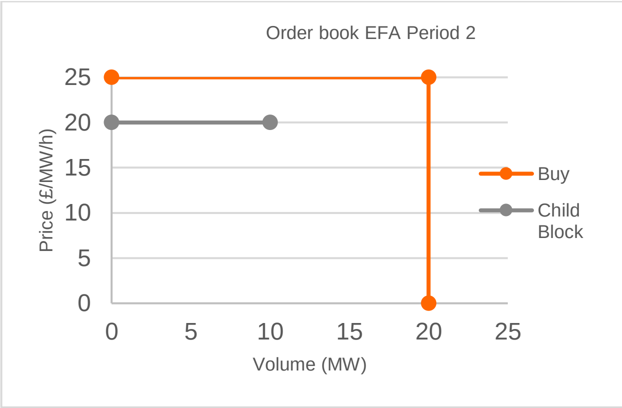
2. A child block cannot be accepted in case its parent is rejected

In this example, we will assume that there is:

- One buy order of 5 MW submitted at £15 MW/h on period 1
- One buy order of 20 MW submitted at £ 25 MW/h on period 2

The parent order is rejected because it is not curtailable and there is no sufficient demand on period 1. Therefore the child order cannot be accepted, even if there is unmet demand at a compatible price.





3. <u>A parent block which is out-of-the-money can be accepted in case its child blocks provide sufficient surplus to at least compensate the loss of the parent.</u>

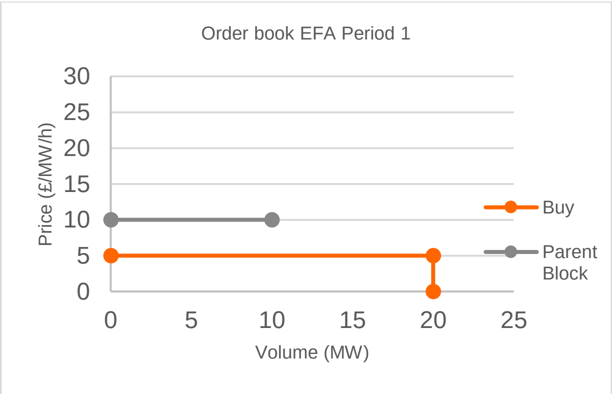
In this example, we will assume that there is:

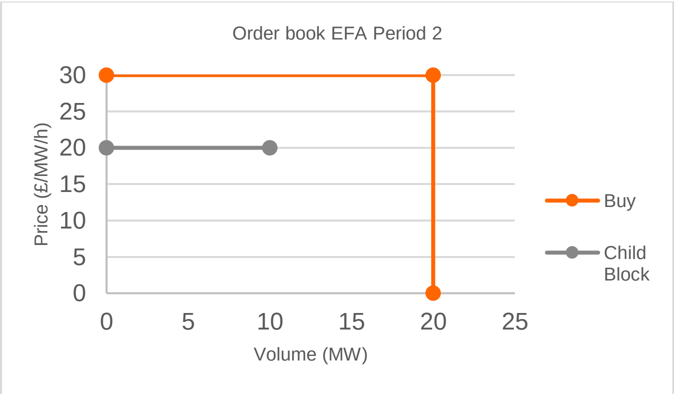
- One buy order of 20 MW submitted at £5 /MW/h on period 1
- One buy order of 20 MW submitted at £30 /MW/h on period 2

On period 1, the price can be at most £5 /MW/h. The parent order would be out-of-the-money and its acceptance would generate a loss of 4h *10 MW * (10 - 5) £/MW/h = £ 200.

On period 2, the price can be at most £ 30 /MW/h. The child order maximum surplus if accepted is (4h*10 MW * (30 - 20) £/MW/h = £ 400) which is higher than the loss generated by the possible acceptance of the parent.

Thus, the parent block which is out-of-the-money can be accepted because its child block can provide sufficient surplus to at least compensate its loss.

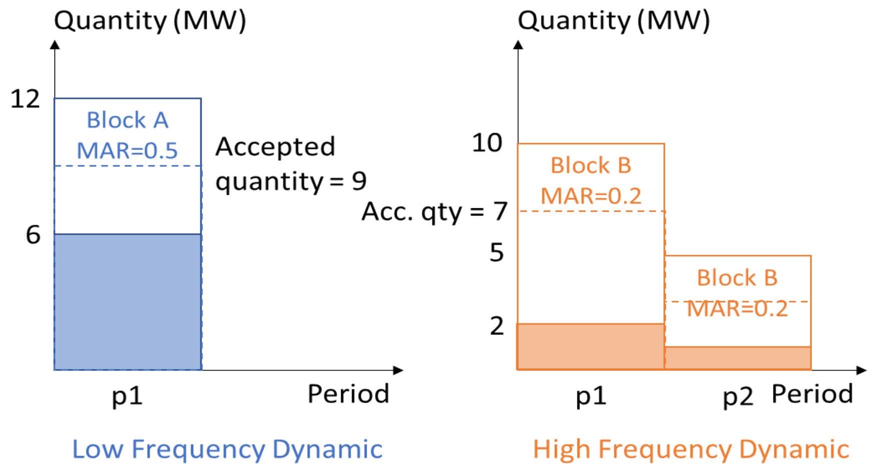




7. Annex: Loop blocks clearing conditions

Let us consider 2 blocks - A and B part of the same loop family.

The two blocks are submitted for different products.



For loop families, the two block orders must have the same acceptance ratio. Let us assume it is 0.75 for this example.

In addition, for multi-period blocks, the acceptance ratio must be the same for all the periods. Therefore:

	Block A	**Block B, p1**	**Block B, p2**
Max quantity (MW) (input)	12	10	5
MAR (input)	0.5	0.2	0.2
Min quantity (MW) (input)	6	2	1
Acceptance ratio (output)	0.75	0.75	0.75
Accepted quantity (MW) (output)	9	7	3

8. Annex: Price minimization

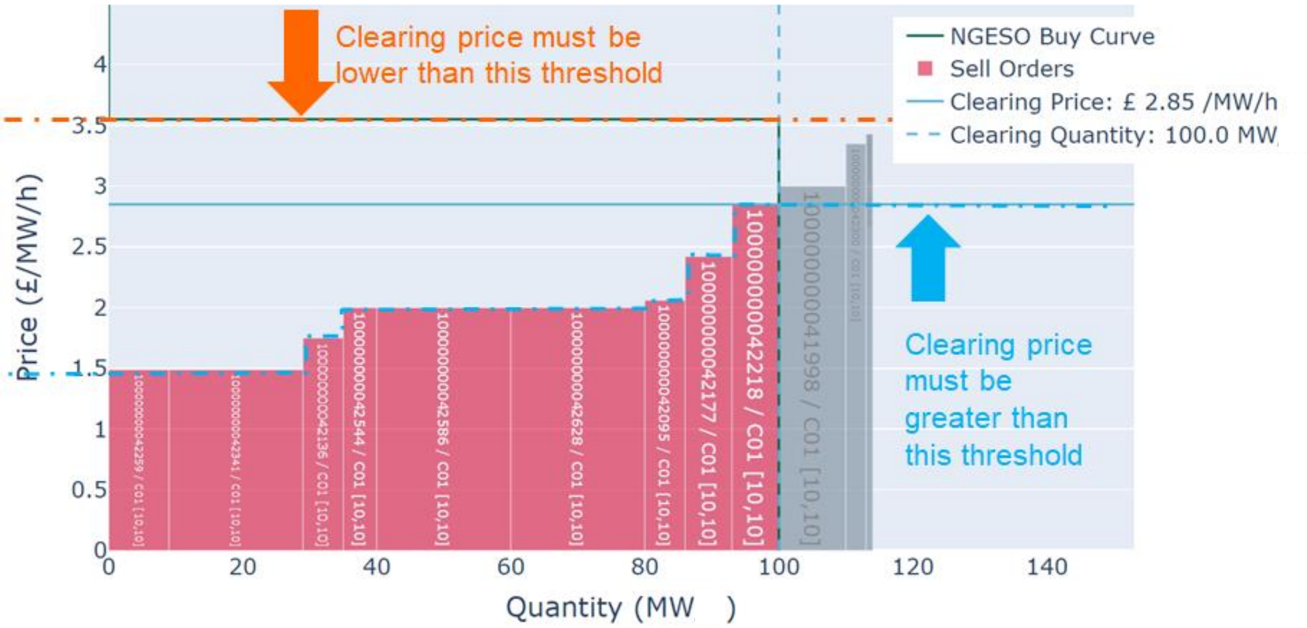


Figure 6 Price minimization - FRA LFS, auction 2020-08-14 EFA period 10

The clearing price could be set anywhere between the 2 limits.

This price minimization selects the lower limit. Price minimization does not change the total welfare but the split of welfare between buyers and sellers.