

I-SEM Trialling of EUPHEMIA: Preparation of Initial Phase Trial Datasets



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The purpose of this document is to provide members of the *I-SEM EUPHEMIA Industry Working Group* with an outline of the assumptions and methodologies used by SEMO to develop the datasets used for the initial conceptual EUPHEMIA trial. The assumptions and methodologies set out herein are provided for information purposes only and do not indicate any preference by EirGrid Group for any particular market design. Whilst every effort is made to provide information that is useful, and care is taken in the preparation of the information, EirGrid Group gives no warranties or representations, expressed or implied, of any kind with respect to the contents of this document, including, without limitation, its quality, accuracy and completeness. EirGrid Group hereby excludes, to the fullest extent permitted by law, all and any liability for any loss or damage howsoever arising from the use of this document or any reliance on the information it contains. Use of this document and the information it contains is at the user's sole risk.

2. EXECUTIVE SUMMARY

In the SEM, participants submit a complex set of data to the market outlining technical data and their fixed and variable costs. SEMO then uses the Market Scheduling and Pricing (MSP) algorithm to determine when and at what MW level they receive a market position, and that all submitted costs are recovered.

The EUPHEMIA algorithm does not explicitly take this technical data into account (with minor exceptions in some order types); therefore, participants must build their technical characteristics into their orders. EUPHEMIA also does not, in most cases, allow fixed costs to be separately stated in a way which guarantees they will be covered if the order is accepted; they too must be built into orders. Using EUPHEMIA, participants may need to make more decisions around timing of bids and implicit cost allocation than in the SEM. EUPHEMIA has a number of different order types which may provide a level of flexibility with which to incorporate technical and commercial characteristics.

The Initial Phase of the I-SEM trialling of EUPHEMIA examined the means of representing SEM style bids in EUPHEMIA order types. The goal of this work was to determine if EUPHEMIA orders could produce a schedule in line with the principles of the SEM. The main principles examined were that generators would be run in a technically feasible and economically advantageous way, i.e. generators do not operate at a loss, and that all demand is fully inelastic and is met in each trading period.

SEMO's expertise of the SEM and knowledge of the EUPHEMIA algorithm were used to convert SEM style bids into EUPHEMIA style orders, in conjunction with the PCR algorithm working group, utilising the different order types available in EUPHEMIA. Initial datasets for three trading days were created, using actual SEM data, each with a number of trial cases concentrating on different order types. The majority of the work in this exercise was in preparing the orders for the thermal generators (c. 50 units) and particularly the non-peaker units (c. 25 units). This was due to the complexity of incorporating the technical and commercial data they submit to the SEM into their EUPHEMIA orders. Orders for all participants were collected and converted into datasets suitable for submission to the algorithm. This process was replicated to create a batch based on a month's worth of data.

The work involved in preparing these datasets included the following:

- Determining trading days to be trialled and sourcing data;
- Establishing assumptions for the cases;
- Creating unit MW profiles utilising SEM Technical Offer Data (TOD);
- Fitting the participant profiles to demand, where applicable;
- Applying SEM Commercial Offer Data (COD) to each participant profile and creating orders in the format typical of EU market interfaces.

3. INTRODUCTION

The I-SEM trialling of EUPHEMIA is an on-going analysis project being completed by SEMO as part of the I-SEM Project. At a high level, the goal of this project is to trial representation of the I-SEM in EUPHEMIA using existing SEM data. As part of this process, it was necessary to create trial datasets in an appropriate format using SEM data. This document explains the assumptions, methodologies and rationale behind the creation of the initial phase I-SEM trialling of EUPHEMIA datasets.

Section 2 provides an executive summary to this document.

Section 4 provides a general outline of the order types considered as part of this exercise.

Section 5 states the general assumptions which were taken in order to facilitate the creation of the datasets.

Section 6 provides information on the source of the data used for this exercise and explains any work which was required to allow the data to be used.

Sections 7 and 8 explain the methods used to develop the EUPHEMIA orders, including: the development of hourly order for each quantity data which respects the technical characteristics of each unit and the application of the commercial characteristics of each unit.

4. OVERVIEW OF ORDER TYPES

Following research and an assessment of EUPHEMIA order types, it was decided that Simple Orders, Flexi Orders, Linked Block Orders, Complex Orders and Exclusive Group Block Orders would be investigated. Merit Order and PUN Orders were not investigated as they are specifically used for the Italian (GME) market and are deemed to not be applicable to the I-SEM design.

Table 1 outlines the initial opinions formulated on how well the technical and commercial characteristics may be incorporated into each order type following a rough assessment of the public information available.

Technical / Commercial Characteristic	SEM MSP Software	Simple Orders	Flexi Orders	Linked Block Orders	Complex Orders	Exclusive Group Block Orders
PQ pairs	✓	✓	~	✓	~	~
No-Load Cost	✓	~	✓	✓	~	✓
Startup Cost	✓	~	✓	✓	✓	✓
Min On Time	✓	✗	~	✓	✗	✓
Min Off Time	✓	✗	~	✗	✗	~
Ramping	✓	✗	✗	✓	✓	✓
Loading	✓	✗	✗	✓	✗	✓
MSG	✓	✗	~	✓	~	~
Soak/Dwell Times	✓	✗	✗	✓	✗	✓
Price Setting	✓	✓	✗	✗	✓	~

Table 1 Subjective assessment of ability for EUPHEMIA order types to represent SEM TOD and COD

4.1. SIMPLE ORDERS

Simple Orders were used for all supplier units, wind, predictable price taker, hydro and peaker thermal generation units.

Simple Orders are the most basic level of EUPHEMIA orders, involving the submission of price-quantity pairs for a unit in each hour. The way in which this is achieved is the submission of a curve including all desired price-quantity pairs for an hour in a monotonically increasing (for sales) or decreasing (for purchases) order for price. Two kinds of curves can be handled by EUPHEMIA: Linear Piecewise, and Stepwise. For this exercise, stepwise curves, where the volume term is delimited by an initial price and a final price which are equal, were chosen as it most accurately represents current SEM format.

The means of representing units with stepwise curves in EUPHEMIA orders is different to that of SEM bids. In the SEM curves, the intended interaction with price floor and price cap in the market does not need to be explicitly stated, as they are inferred in the Market Scheduling and Pricing software. However, with EUPHEMIA this interaction with price floor and price cap must be stated explicitly. Similarly, for a unit to participate as a price maker they must explicitly bid a full curve including price floor, price cap and any intermediate bids.

Units in the SEM which have price taker status agree to receive any price which results from the market run if they are cleared, which implicitly includes price floor and price cap without needing to state these values in the bid submissions. Similarly, price maker units in the SEM implicitly have the price cap and price floor applied to their bids via the SEM pricing algorithm. However, with EUPHEMIA this agreement to accept any price between price floor and price cap must be stated explicitly. Figure 1 and Figure 2 show examples of these order curves for price maker and price taker units respectively.

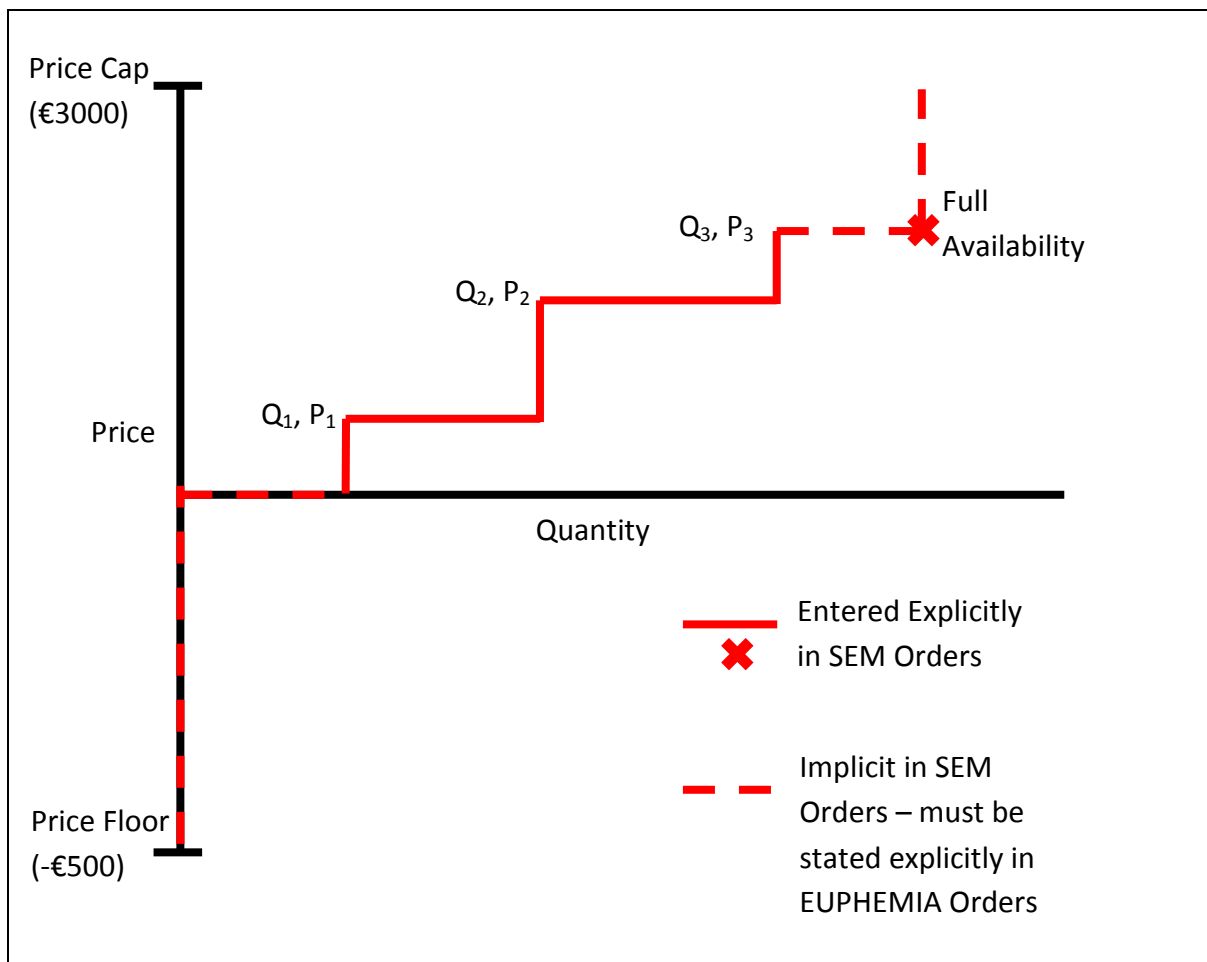


Figure 1 Stepwise curve for price maker unit orders, SEM versus EUPHEMIA

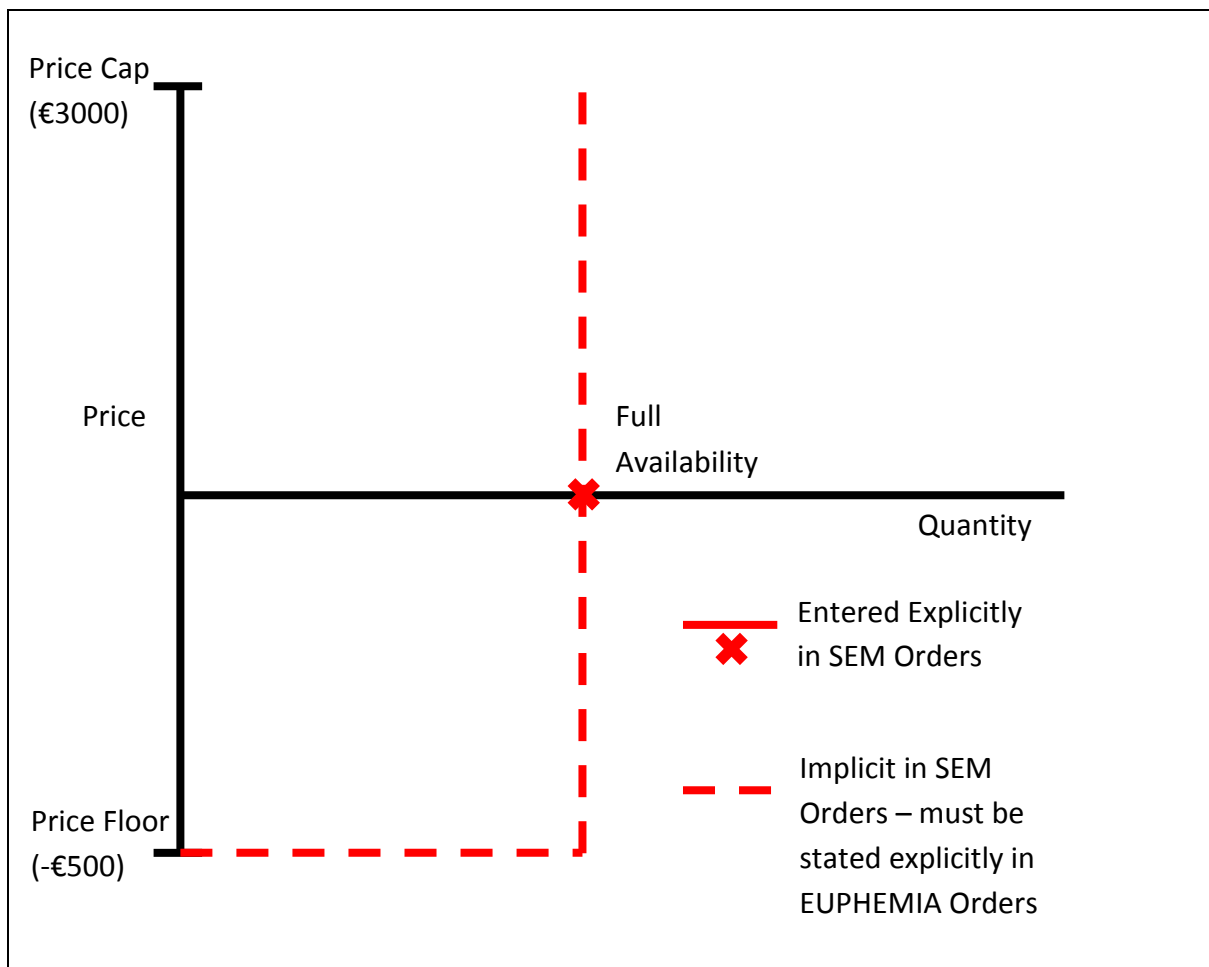


Figure 2 Stepwise curve for price taker unit orders, SEM versus EUPHEMIA

4.2. FLEXI ORDERS

Flexi Orders were used for all demand side units (DSUs).

Flexi Orders are where a unit submits a simple block order (e.g. a single Price-Quantity pair covering one hour), but does not specify what time that order should be taken. The participant submits a range of hours within which they would be happy for the order to clear, and leaves it up to the market to select in which hour of the trading day to place the order.

4.3. LINKED BLOCK ORDERS

Linked Block Orders were one of three order types used for baseload and mid-merit (i.e. non-peaker) thermal generation units, or units identified as being peakers but with Min-On time of greater than one hour. They were also used for some Pumped Storage hydro unit cases.

These are a set of block orders with a linked execution constraint which form a “family” hierarchy of execution. This family includes generations such as the parent block, child block, grandchild block etc. A parent block order is one where the clearing of a child block directly depends on its own execution. A child block can be cleared only if the parent block order to which it is linked is also cleared, similarly for a grandchild block and the child block to which it is linked, etc. However, it is possible that a child block can force the parent block to clear where the surplus revenue on the child block covers the costs of the parent.

Linked blocks allow financial and technical constraints of plants to be incorporated into the order for a particular hour (such as startup costs and ramping characteristics, different fuel costs for different output levels). They can be used in situations where the quantity in one hour depends on the quantity in another, such as a unit whose main goal is to come on for peak demand offering to stay on in hours after the peak if it achieves its initial goal. Linked blocks can have fixed volume levels or profiled levels, i.e. different quantities in each hour for one block.

Block orders have a parameter called the Minimum Acceptance Ratio (MAR), which outlines the minimum volume of the block which must be accepted, and can be in percentage % or MW form. For example, a 100MW block with a MAR of 50% or 50MW can be accepted for any volume between 50 and 100MW.

4.4. COMPLEX ORDERS

Complex Orders were one of three order types used for baseload and mid-merit (i.e. non-peaker) thermal generation units, or units identified as being peakers but with Min-On time of greater than one hour.

A Complex Order is similar to a stepwise hourly simple order, but with additional constraints which increase the complexity of the order. In addition to submitting monotonically increasing price-quantity pairs in each hour, the participant can submit some or all of the following:

- Minimum Income Condition (MIC):
 - o This is an economic condition which covers the whole trading day in which the participant is submitting orders, where the order in question is only considered submitted for matching purposes if the seller obtains a minimum income. In other words, the order will firstly be matched as if it were a simple bid, and then a check carried out of whether over the course of the trading day those successful orders matched or exceed the unit’s Minimum Income Condition. If they do the entire bid will be accepted, and if they do not the entire bid will be rejected.

- This serves a different function to the submission of fixed costs in SEM bids. In the SEM, the unit's position in the merit order is determined through its PQ pairs, and if they are cleared in the market their costs are covered additionally through uplift. The MIC's function is to check whether the prices and generation levels achieved by the generator over the trading day are sufficient to cover their fixed and variable costs. If they are not sufficient, it rejects all orders for that generator for that market day.
- The MIC comes in two components: Fixed (€) representing the fixed costs of the unit, and variable (€/MWh) representing the variable costs the unit. The prices and quantities matched in the market are multiplied and summed over the day, being compared with the fixed and variable components of the MIC condition through the following equation:

$$T_f + T_v \cdot \left(\sum_h \sum_{o \in h} [g_o \cdot x_o] \right) \leq \sum_h \left(MCP_h \cdot \left(\sum_{o \in h} [g_o \cdot x_o] \right) \right)$$

where T_f is the MIC fixed term, T_v is the MIC variable term, g_o is the generation level of unit o , x_o is the on/off state of unit o , and MCP_h is the market clearing price in the hour in question.

- Scheduled Stop Condition:
 - This condition allows the unit, if it is already on at the start of the trading day and its MIC order is rejected, to have part of the order (within the first three hours of the trading day) remain cleared in the market as a simple order. This is to allow a unit to at least come off in the event it is unsuccessful in its MIC order, and there is a requirement that the quantities decrease hour-on-hour.
- Ramping Conditions/Increase and Decrease Gradient Conditions:
 - This condition establishes for each production unit a maximum upward and/or downward difference in energy variation between two consecutive hours (MW/h). There are separate ramping up and ramping down conditions, but only a single figure for each can be submitted.

4.5. EXCLUSIVE GROUP BLOCK ORDERS

Exclusive Group Block Orders were one of three order types used for baseload and mid-merit (i.e. non-peaker) thermal generation units, or units identified as being peakers but with Min-On time of greater than one hour.

An Exclusive Group of block orders has been assumed to be interpreted as a set of blocks, each block covering a number of hours, within which a maximum of one block can be matched. This is achieved through a MAR feature similar to that in linked blocks: a constraint is placed in the optimisation to that the sum of the MAR for cleared orders in an

exclusive group must be less than or equal to 100%. Therefore, each block in the group has a MAR greater than 50%, only one block will clear.

The final cleared block will be one of a subset of the blocks in the group which are determined to be “in the money” (its submitted price is in merit, below the average market price for generator unit, above for demand unit) and will be the block which best optimises the total welfare among all blocks “in the money” in the exclusive group. It is important to note that this means the block selected may not be the one which results in the maximum profit for the participant. It is not yet possible to mix linked blocks and exclusive block groups.

This kind of order can be used to propose different production patterns for trading in order to increase chances of having a block executed. For example, a generator unit can submit different profiles (starting up later, shutting down earlier, outputting at different MW levels etc.) with different prices for the same delivery day, in the hope that one will be selected to be matched. The blocks can be profiled, but there can only be one price per block.

5. ASSUMPTIONS

An assumption was made that all participants would order in the DAM, and that these orders would be at their max capacity or full forecast availability. While this may not reflect the actual trading strategies and schedules which would arise in the I-SEM, as the aim of this work was to compare with results from the SEM, the level of participation in the SEM was assumed.

There is a difference between SEM and EUPHEMIA in the start time of the trading day. In the SEM, 06:00 GMT (or 07:00 CET) is the first hour, while in EUPHEMIA 23:00 GMT (00:00 CET) is the first hour. If SEM data for a time period of 23:00-23:00 GMT was to be taken, SEM data for two trading days would have to be used with potential differences in the TOD and COD submitted by each unit in each day, adding complexity to the exercise and making comparison against the actual SEM results more difficult.

For simplicity, SEM trading day data was taken, with data being shifted from the first SEM market hour to the first EUPHEMIA market hour, for example: data for the first SEM market hour at 06:00 on 03/03/2014 was shifted to the first EUPHEMIA market hour at 23:00 02/03/2014 (i.e. 00:00 on 03/03/2014 for CET, start of the EUPHEMIA trading day). The same approach was taken for forecast data. This may result in different outcomes, especially concerning cross border flows, than would actually happen because of demand and wind curves are out of sync with those of the other coupled markets; however, for comparison with SEM results it provided the best solution.

The creation of all EUPHEMIA orders was done in a way to ensure that the resulting

scheduled MW levels would not require a unit to maintain output at less than its minimum stable generation (MSG) level. There are some cases where order quantities less than MSG in an hour are necessary and technically feasible, such as during loading and deloading.

It was assumed that quantity parameters would be rounded to 1 decimal place (0.1MW) and price parameters would be rounded to two decimal places (0.01€/MWh).

Minimum-off Time data was not taken into account in the creation of EUPHEMIA orders. This was in order to reduce the number of permutations involved and reduce complexity in profiling and pricing. If min-off times were considered, the permutations of order cases for units which reduce their output to zero during the trading day would need to extend to possibilities of them coming back on in any technically feasible hour.

Supplier units, wind units and predictable price taker units were all assumed to be price-takers. Their orders, therefore, consisted of a single MW quantity for each market hour from their TSO forecasts or nomination profile with appropriate accounting of price cap and price floor. Although the European day-ahead market is two sided, with supplier participants able to participate actively in many separate units and submit desired prices, they were assumed to behave as price-takers to most accurately represent the SEM, enabling comparison of results with actual schedules.

There is no explicit means of including energy limit information in EUPHEMIA orders. Therefore, the quantity submissions for hydro unit orders were developed in a way which took each unit's energy limit into account for the relevant trading day. Three categories of units were used to determine the method used to develop each unit's order quantities:

- Units whose energy limits were large enough were assumed to have order quantities equal to their full availability in every hour.
- Units whose energy limits allowed them to generate at full availability in most but not all hours (e.g. < 5hrs where it couldn't generate at full availability) were assumed to have order quantities equal to their full availability in most hours. In other hours the quantity was determined by taking into account the number of hours determined through calculating an integer for the remaining hours which would allow the unit to generate in all hours of the day while respecting the energy limit on the unit. The hours at full availability were concentrated towards the middle and end of the market day to reflect offer behaviour to maximise revenues.
- Units whose energy limits only allow them to generate at full availability for a few hours in the market day (e.g. < 15hrs), were assumed to have order quantities equal to their full availability for every possible hour. In all other hours, their order quantities were 0MW.

All hydro units were assumed to have one price for a trading day, derived using their COD submitted to the SEM and taking their energy limits into account.

Pumped storage hydro units were modelled separately, with the Turlough Hill common reservoir taken into account in bid formation in a way that each unit's actions take into account a quarter fraction of the reservoir. For example, each unit's bid to buy could only have the unit pump the reservoir up to a quarter of the amount required to make it full, so that if the orders for all four units clear, the sum of their actions leads to the full filling of the reservoir. This was similarly taken into account for generating and reducing reservoir level towards its target or minimum levels.

Because pumped storage units do not submit COD in the SEM, it was not possible to derive prices for their orders in a similar manner to other units. Because of this limitation, the prices used for pumped storage units this exercise were estimated in a manner less robust than for other order types, which could potentially result in differences in how pumped storage participants are scheduled versus other participants.

Profiling for thermal generators using their TOD submitted to the SEM was done firstly on a minute-by-minute basis before being converted into average hourly figures compatible with EUPHEMIA. This approach takes the output from the previous minute and adds/subtracts the change in output which would occur from one minute of the event the unit is experiencing to determine its output for the subsequent minute. It was assumed that the minute-by-minute approach had adequate accuracy for the purposes of this exercise and was the easiest approach for automating the process of profiling units. It was assumed that if the unit were to follow this profile generated using its TOD, it would not be in imbalance with its hourly quantity submissions to the market.

Thermal units which are already on at the start of the trading day use the last MW status in their SEM bid submission as their MW output in the first minute of their minute-by-minute generator profile, which is used to develop their hourly trade quantities. They do not include startup costs in their orders, but continue to include fixed no-load costs and ramping down/shutdown profiles. Units which were on but at less than their max availability also include ramping up profiles in their orders.

Thermal peaker units were assumed to behave differently to the other thermal units, due to their fast ramping capabilities. They are assumed to submit the same quantity order in every hour, which takes into account their ramping up, staying on at max, ramping down and shutting down. It is assumed that they are starting from being off in every hour; therefore, startup costs must be included in their order prices in every hour.

6. DATA

Data was required for every participant in the market, including:

- Wind Units;
- Supplier Units;
- Demand Side Units (DSUs);
- Interconnector Units;
- Hydro Units;
- Pumped Storage Units;
- Thermal Units; and
- Predictable Price Taker Units.

The data used was based on market submissions (TOD and COD) and forecasts in the Ex-Ante 1 (EA1) timeframe where available – otherwise the best available data was used. The EA1 timeframe was chosen as it represents the time at which Day-Ahead Market orders would be submitted. The dates assumed for this exercise were the 3rd, 19th and 23rd of March, 2014. These days were chosen in order to get a variation in terms of wind and demand profile: the 23rd is on a weekend while the others are weekdays; the 19th has a high wind forecast throughout the day; and the 23rd has a large variation in forecasted wind profile across the day. Figure 3, Figure 4 and Figure 5 show the hourly wind and load profile for 03/03/2014, 19/03/2014 and 23/03/2014 respectively.

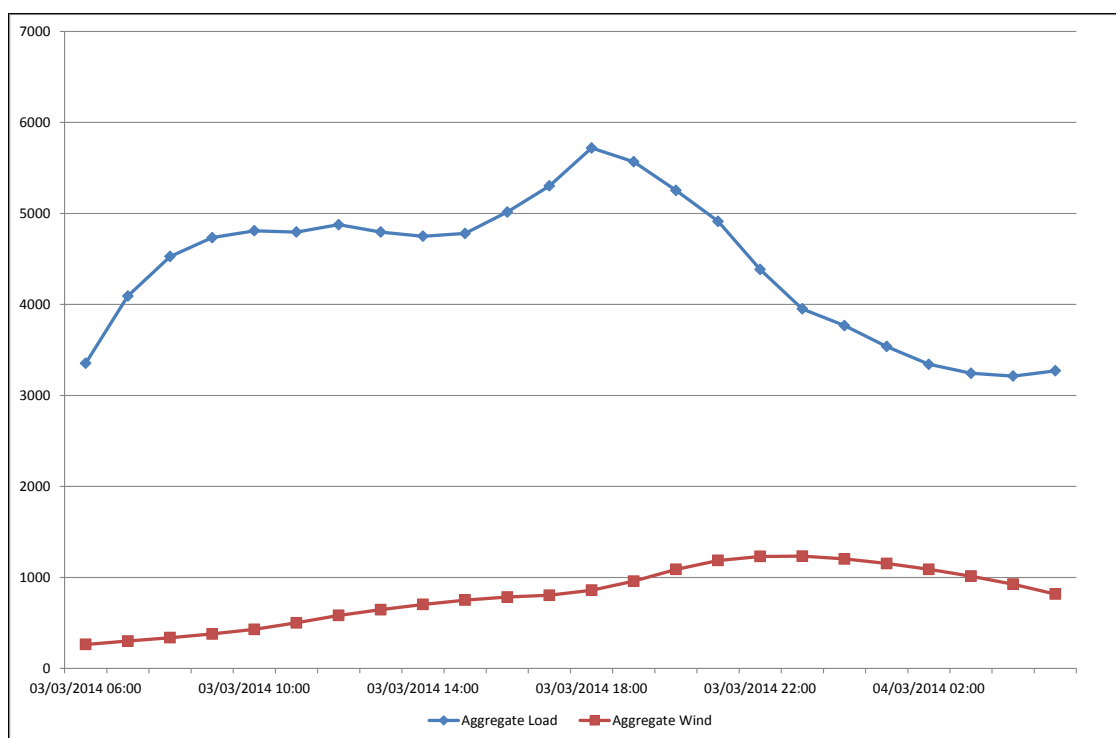


Figure 3 System load and wind output March 3rd 2014

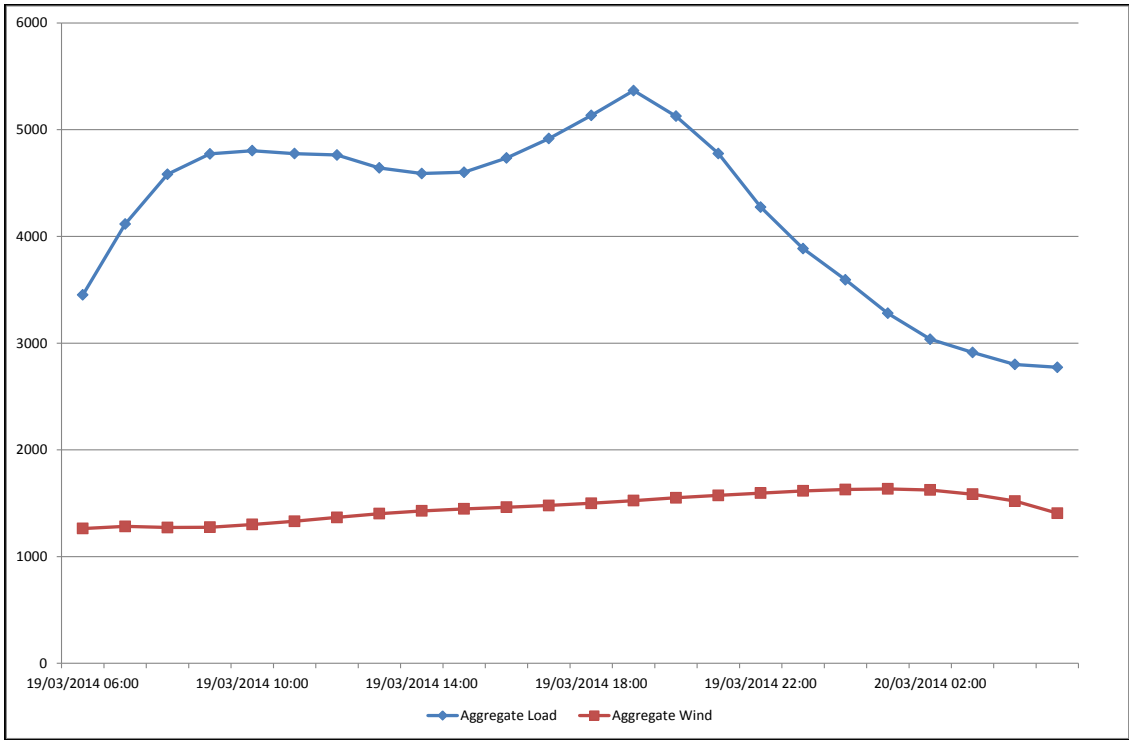


Figure 4 System load and wind output March 19th 2014

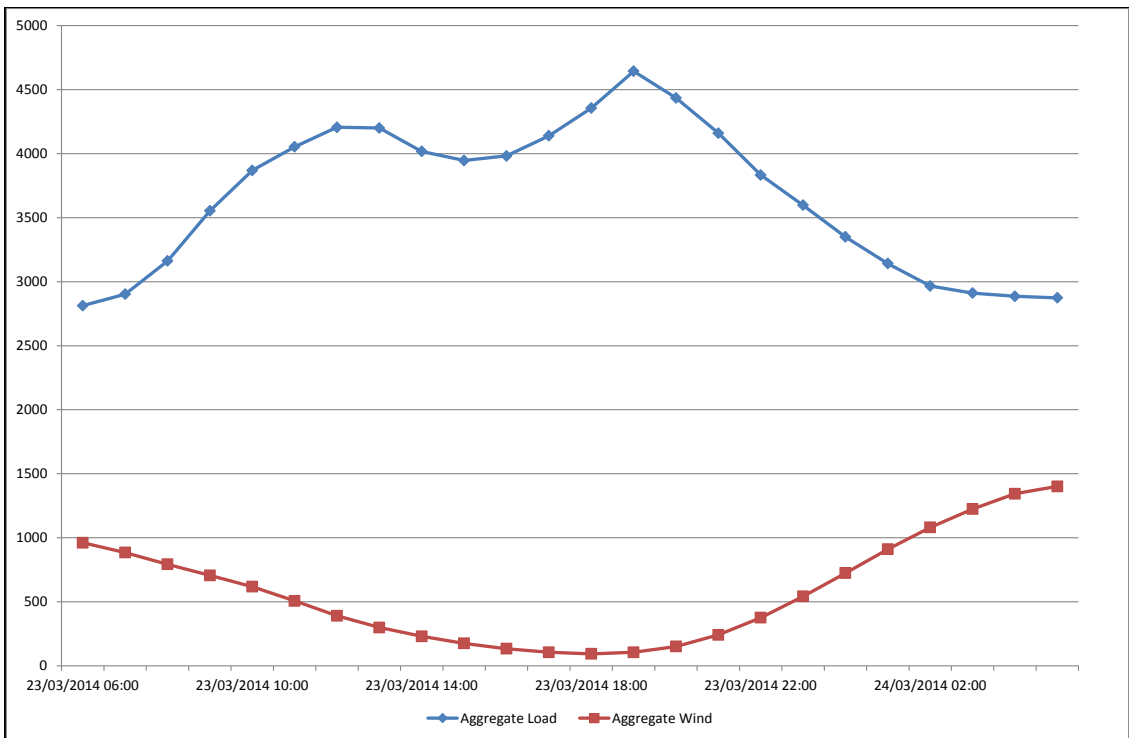


Figure 5 System load and wind output March 23rd 2014

Real SEM bid data was used so that the unit schedule resulting from these EUPHEMIA trials could be compared against actual SEM market schedule results.

The data used for wind and supplier units were taken from TSO forecasts. In these forecasts, data is given for two delivery intervals in each hour: the first of these were chosen every time (i.e. the one “on-the-hour”). Each wind generation unit was represented separately, while two supplier units were used: one to represent demand in Ireland and one for Northern Ireland. No commercial data was used as they were modelled as price-takers in the order formation.

The profiles of predictable price taker units were based on their actual nomination profiles for those days, with no commercial data required due to their price-taker nature.

All interconnector participation in the trial cases is determined by the results of the implicit allocation of capacity in EUPHEMIA, rather than explicit interconnector orders as in the SEM. Interconnector ramp rates were included, taken from the rates currently in operation, in applicable trial cases.

Pumped storage units don’t submit commercial data, as their operation is optimised within the SEM scheduling software. Their TOD submitted in the EA1 was considered, including ramping rates, capacities etc. Reservoir level data (in terms of energy MWh) including the initial level at the start of the trading day, the target level for the end of the day, the maximum and minimum levels, were sourced from the EA1 run datasets. The reservoir data was for all pumped storage units while each individual unit was modelled separately – this was taken into account in the calculation of the order quantities for each unit. Data for the previous day was also needed as the end reservoir levels of the previous day were taken as the start reservoir levels of the next day. Actual SEM prices for the days in question and the cycle efficiency (70%) of the unit were used in some of the scenarios to determine order prices.

The data from the TOD and COD submitted by participants in the SEM contains explicit characteristics of the units which must be taken into account in the formation of quantity profiles and prices in the completed orders. The data used in the formation of orders for each dataset includes the following:

- Price Quantity (PQ) pairs (possible to submit up to four pairs);
- Startup costs for 3 different heat states (hot, warm, cold);
- No-Load cost;
- Data from which the initial condition and heat state of the unit can be derived including last status (on/off), last MW, last time the status changed and first time unit is available again, cooling boundary times for 3 different heat states;
- Block load for 3 different heat states;

- Load up rate and breakpoint levels for 3 different heat states (possible to submit up to three);
- Soak up time and breakpoint levels for 3 different heat states (possible to submit up to two);
- Minimum Stable Generation (MSG) level;
- Ramp up rate and breakpoint levels for 3 different heat states (possible to submit up to five);
- Dwell up time and breakpoint levels for 3 different heat states (possible to submit up to five);
- Max availability;
- Min On Time;
- Ramp down rate and breakpoint levels for 3 different heat states (possible to submit up to five);
- Dwell down time and breakpoint levels for 3 different heat states (possible to submit up to five);
- Deload rate and breakpoint levels.

This gives an indication of the level of complexity which participants must build into the formation of their EUPHEMIA orders.

A number of sources of information were used to develop the methodologies for the creation of orders, including:

- Public description and clarification of EUPHEMIA (for general information on EUPHEMIA and order types): http://www.eirgrid.com/media/PCR_EUPHEMIA_CLARIFICATION.pdf
- Presentation on smart blocks (for further information on possible means of utilising linked and exclusive group block orders): <http://static.epexspot.com/document/25495/Smart%20blocks%20-%20presentation>
- Regulatory Authorities presentation on the I-SEM High Level Design (with information gained from interactions with Power Exchanges on the possible means of utilising different order types): <http://www.allislandproject.org/GetAttachment.aspx?id=ba807cb2-9dff-4196-b1e8-41c3c8f5bf57>
- Where available, the format used by N2EX's Sapri software was used for the initial Power Exchange – Participant interface creation of orders before they were converted to a form compatible with inputting directly into the EUPHEMIA algorithm: https://www.n2ex.com/digitalAssets/91/91615_n2ex---sapri-trade-user-guide-2014-v4.pdf
- These formats were not available for complex orders. Publically available information on the Iberian market was used: http://www.omel.es/files/reglas_agosto_2012_ingles.pdf

7. METHODOLOGIES

7.1. GENERATOR PROFILING

The purpose of the profiling work was to ensure the quantity data submitted by units to EUPHEMIA respected the technical characteristics of the unit which can prevent units from being in imbalance.

The source data and behaviour for thermal units (both peaker and non-peaker) was more complex and developing their generator profiles required more work than was required for wind generators, supplier units etc. For example, TOD and COD submitted by these units to the market do not prescribe a quantity figure for a particular hour like forecasts; this is determined by the market systems in the SEM.

In order to facilitate the creation of different profiles for each thermal unit, the MW output a generator should be doing for each minute was calculated, based on its initial conditions (already on, or off and hot/warm/cold), its output in the previous minute, its submitted TOD, and the events occurring (e.g. during ramping, soaking, deloading etc.).

The method takes the unit from a certain MW level (e.g. 0MW if they are off, their last updated MW output level, or another manually entered level) to their desired MW level (for example their max availability) and keeps them there for a time. If the unit was already on, then it is kept at its desired level for an explicitly stated amount of time. If it was off, it is kept at its desired level for at least its minimum-on time, and then for any desired explicitly stated additional time.

This approach results in a profile of MW values for every minute, bringing a unit from a start point to an end point while properly taking into account all appropriate technical characteristics and output behaviours of the unit. From this the average over each hour can be created (in this case using an indexing system and a pivot table) which is both compatible with EUPHEMIA and equals the volume of energy generated by the actual output profile of the unit.

The approach adopted mirrors closely the method used in the calculation of instruction profiling for the SEM, set out in Appendix O of the Trading & Settlement Code.

7.2. CREATION OF ORDERS – WIND, PREDICTABLE PRICE TAKER, SUPPLIER, DSU, HYDRO UNITS

The source data and assumptions around some participant types simplified the exercise of applying their commercial characteristics and the creation of orders in EUPHEMIA format.

- Wind units and predictable price taker units were assumed to offer at price floor of -€500 in every hour regardless of quantity in order to replicate their price taker nature in the SEM. They both use only simple orders, which require the orders to be created in a stepwise Price-Quantity curve with monotonically increasing price; similar to what is shown in Figure 6. Note that in the format used, order quantities for offers to generate are seen as negative values, and bids for demand are seen as positive values.

Anon Portfolio	Market Day	Period	GMT/BST	-500	-500	3000
22	03/03/2014	1	23:00-00:00	0	-0.8	-0.8
22	03/03/2014	2	00:00-01:00	0	-0.8	-0.8
22	03/03/2014	3	01:00-02:00	0	-1	-1
22	03/03/2014	4	02:00-03:00	0	-1.1	-1.1
22	03/03/2014	5	03:00-04:00	0	-1.4	-1.4
22	03/03/2014	6	04:00-05:00	0	-1.8	-1.8
22	03/03/2014	7	05:00-06:00	0	-2.4	-2.4
22	03/03/2014	8	06:00-07:00	0	-3	-3
22	03/03/2014	9	07:00-08:00	0	-3.5	-3.5
22	03/03/2014	10	08:00-09:00	0	-3.9	-3.9
22	03/03/2014	11	09:00-10:00	0	-4	-4
22	03/03/2014	12	10:00-11:00	0	-4	-4

Figure 6 Price taker generation simple orders

- Demand (Supplier) Units were also assumed to be price takers and therefore bid in at price cap of €3000. They used simple orders also, with the PQ curve created as shown in Figure 7.

Anon Portfolio	Market Day	Period	GMT/BST	-500	3000	3000
160	03/03/2014	1	23:00-00:00	926.6	926.6	0
160	03/03/2014	2	00:00-01:00	1125.4	1125.4	0
160	03/03/2014	3	01:00-02:00	1223.7	1223.7	0
160	03/03/2014	4	02:00-03:00	1139	1139	0
160	03/03/2014	5	03:00-04:00	1277	1277	0
160	03/03/2014	6	04:00-05:00	1284.1	1284.1	0
160	03/03/2014	7	05:00-06:00	1300.5	1300.5	0
160	03/03/2014	8	06:00-07:00	1265.7	1265.7	0
160	03/03/2014	9	07:00-08:00	1270.8	1270.8	0
160	03/03/2014	10	08:00-09:00	1270.1	1270.1	0

Figure 7 Price taker demand simple orders

- Demand Side Units were assumed to use flexi orders, making their max availability for any one hour interval of the day, and using commercial data to formulate their price. In their SEM COD, they submit only one price and quantity pair, therefore this was the price taken for their EUPHEMIA order. The flexi orders were created as shown in Figure 8.

Date	Anon Portfolio	Order Ref	User Ref	Interval	From Hour	To Hour	Price	Volume
03/03/2014	6			1	01	24	€ 454.84	-49
19/03/2014	6			1	01	24	€ 410.17	-72
23/03/2014	6			1	01	24	€ 410.17	-72
03/03/2014	65			1	01	24	€ 375.54	-13
19/03/2014	65			1	01	24	€ 389.00	-9
23/03/2014	65			1	01	24	€ 389.00	-9

Figure 8 Demand side unit flexi orders

- Hydro Units were assumed to use simple orders, with the number of hours in which they submitted a volume other than 0MW depending on whether they were energy limited or not. For all hydro units commercial data was used to formulate their price, with only one price-quantity pair being submitted in their SEM COD. The prices of energy limited units were adjusted to reflect the reduced volume they could generate versus being scheduled for their full availability in every hour. All hydro units used simple bids, with the PQ curve created as shown in Figure 9.

Anon Portfolio	Market Day	Period	GMT/BST	-500	8.4	3000
36	03/03/2014	01	23:00-00:00	0	-4	-4
36	03/03/2014	02	00:00-01:00	0	-8	-8
36	03/03/2014	03	01:00-02:00	0	-8	-8
36	03/03/2014	04	02:00-03:00	0	-8	-8
36	03/03/2014	05	03:00-04:00	0	-8	-8
36	03/03/2014	06	04:00-05:00	0	-8	-8
36	03/03/2014	07	05:00-06:00	0	-8	-8
36	03/03/2014	08	06:00-07:00	0	-8	-8
36	03/03/2014	09	07:00-08:00	0	-8	-8
36	03/03/2014	10	08:00-09:00	0	-8	-8

Figure 9 Hydro unit simple orders

7.3. CREATION OF ORDERS – THERMAL UNITS

Four of the EUPHEMIA order types were identified as being potentially suitable for representing thermal units in the market, and their TOD and COD. Three were identified for non-peaker units: Linked Block, Complex, and Exclusive Group Block orders. The complexity of these order types was used for non-peaker thermal units to represent their ramping capability, Min-On time requirement and likelihood to aim at generating over multiple hours in the day. Separate trial cases and datasets were created to represent all units in each of these order types.

Simple orders were the one order type identified as being most suitable for peaker units, due to their fast ramping capabilities, low Min-On time requirements, and likelihood to be called for short term system stress events.

7.3.1. SIMPLE ORDERS

Simple Orders were used to represent peaker units with min-on time of less than 1 hour. These required a single price and quantity to be submitted together. The quantity was taken

from the data derived in Section 7 which considered the unit coming on, staying on at max, and coming off within one hour. Therefore the same price and quantity could be used in every hour, with the price being calculated from the startup, no-load and PQ pair data submitted with the unit's COD as follows:

Price =

$$\frac{\text{Startup} + \text{NoLoad} + \text{Min}\{Q_1, \text{Quantity}\} \cdot P_1 + \text{Max}\{0, (\text{Min}[Q_2, \text{Quantity}] - Q_1) \cdot P_2\} + \text{Max}\{0, (\text{Min}[Q_3, \text{Quantity}] - Q_2) \cdot P_3\} + \text{Max}\{0, (\text{Min}[Q_4, \text{Quantity}] - Q_3) \cdot P_4\} + \text{Max}\{0, (\text{Quantity} - Q_4) \cdot P_5\}}{\text{Quantity}}$$

where Quantity is the actual hourly quantity to be submitted in the order, and P₁ Q₁, P₂ Q₂ etc. were the Price Quantity pairs from the SEM commercial offer data. Startup costs were included in each hour as it was considered that peaker units would submit in a format that can clear in the one hour of the trading day. This format of the equation guarantees that the fixed costs and the costs which vary with generator output are appropriately incorporated.

This single price and quantity was then used to create the orders in the stepwise curve format required. Figure 10 shows an example of how these orders were created in the PX format.

Anon Portfolio	Market Day	Period	GMT/BST	-500.00	305.07	305.17	3000.00
84	19/03/2014	1	23.00-24.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	2	00.00-01.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	3	01.00-02.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	4	02.00-03.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	5	03.00-04.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	6	04.00-05.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	7	05.00-06.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	8	06.00-07.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	9	07.00-08.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	10	08.00-09.00	0.00	0.00	-82.20	-82.20
84	19/03/2014	11	09.00-10.00	0.00	0.00	-82.20	-82.20

Figure 10 Peaker thermal unit simple orders

7.3.2. LINKED BLOCK ORDERS

For non-peaker thermal units (mid-merit, baseload and units with a min on time > 1 hour), the blocks created for these cases were based on unit's technical and commercial characteristics. It was decided that fixed costs (startup and no-load as applicable) would be built into the price of the parent block, along with the variable price given in the PQ pairs up to MSG.

In general, the different levels of blocks were created in layers representing the following:

- 1st Level: Quantities less than and equal to Min Stable Generation, with the price from the first PQ pair P_1 if the quantity is less than or equal to Q_1 . If MSG MW level is greater than Q_1 , a load weighted average price using P_1 and P_2 was calculated as follows:
 - $$P = \frac{P_1 \cdot Q_1 + P_2 \cdot (\text{MSG} - Q_1)}{\text{MSG}}$$
 - No-load costs for each hour of the block were also incorporated in this generation. For a Parent block, startup costs were also incorporated if the unit was not already on at the start of the trading day. The parent block must clear in order for the other blocks in the trading day to clear, therefore guaranteeing the recovery of fixed startup and no-load costs.
- 2nd Level: Quantities greater than MSG but less than Q_1 , with the price from the first PQ pair P_1
- 3rd Level: Quantities greater than Q_1 but less than Q_2 , with the price from the 2nd PQ pair P_2
- 4th Level: Quantities greater than Q_2 but less than Q_3 , with the price from the 3rd PQ pair P_3
- 5th Level: Quantities greater than Q_3 but less than Q_4 , with the price from the 4th PQ pair P_4
- 6th Level: Quantities greater than Q_4 but less than the max output quantity of the unit (if it exceeds the quantities of all PQ pairs), with the price from the 4th PQ pair P_4

The orders of all units are represented by an initial profile and supplementary profiles. The format of the orders was different depending on whether the unit was already on at the start of the trading day or not.

For units which are not already on at the start of the trading day, an initial profile representing the unit coming on, ramping up to max capacity, staying there for min on time, and ramping down to zero output was created with linked blocks. This is the smallest technically feasible profile for the unit, around which supplementary profiles can be added to extend the running time of the unit.

In the initial profile, the 1st Level block was the Parent block for the unit for that trading day, and therefore included the PQ pairs, no-load and startup costs in the price. The other levels of blocks were the first Children, Grandchildren etc. blocks for the unit for that trading day, representing the PQ pairs submitted to the SEM.

Figure 11 and Figure 12 show an example of the process used to calculate the prices and quantities of the blocks for the initial profile of a unit which was not already on at the start of the trading day, with the unit starting, staying on at max output for min-on time, and then shutting down. The profile for the unit determined in Section 7 is placed in the

“Output” column, with formulae in the other volumes splitting this overall profile into separate blocks representing the generations as explained previously.

		Incremental positions represented					
Hour	Ouput	Parent A	Child A - Parent B	Child B - Parent C	Child C - Parent D	Child D - Parent E	Child E
1	32.436	32.4355	0	0	0	0	0
2	34.690	34.69	0	0	0	0	0
3	50.090	36	14.09	0	0	0	0
4	217.380	36	84	70	27.37966667	0	0
5	258.000	36	84	70	68	0	0
6	258.000	36	84	70	68	0	0
7	258.000	36	84	70	68	0	0
8	230.537	36	84	70	40.53666667	0	0
9	40.996	36	4.995666667	0	0	0	0
10	0.000	0	0	0	0	0	0
11	0.000	0	0	0	0	0	0
12	0.000	0	0	0	0	0	0
		€ 507.40	€ 104.26	€ 112.84	€ 113.81	€ -	€ -

Figure 11 Example of interface used to apply COD to the technical running profile of units to create linked block orders

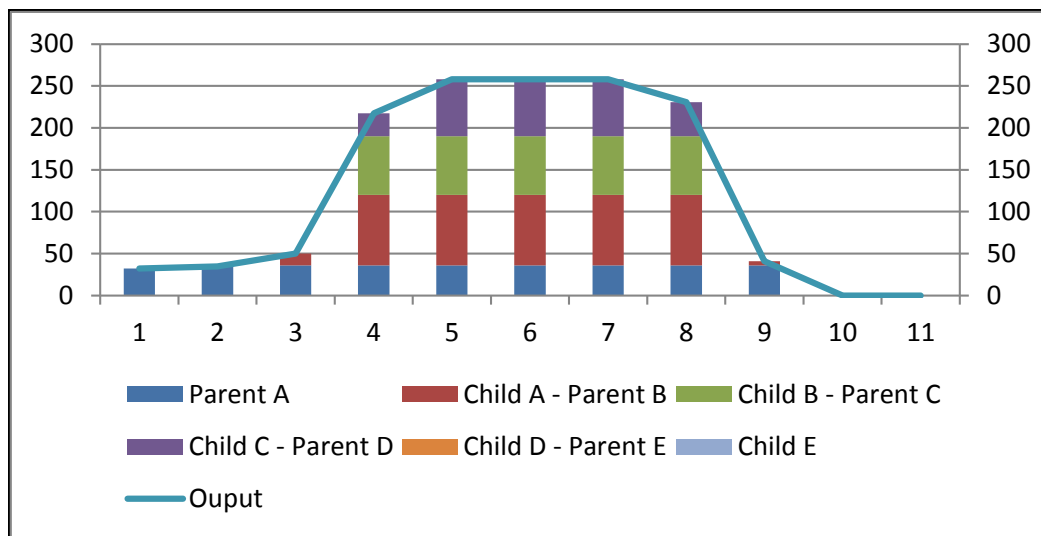


Figure 12 Illustrative example of results from applying COD to the technical running profile of units to create linked block orders

Around the initial profile, supplementary profiles of Children, Grandchildren etc. blocks were added, allowing the unit to extend its running by staying on for more hours or coming on earlier if deemed economically advantageous to do so, all while representing the same SEM TOD and COD characteristics of the unit. For these supplementary profiles of blocks, the fixed no-load cost for those additional hours was built into the price of the 1st Generation blocks (startup costs do not need to be taken into account again).

For units which were not already on, supplementary profiles which represented the startup profile were added before the initial profile. Each of these profiles allowed the unit to come on between 3 and 5 hours earlier depending on the amount of time between the start of the initial profile and the start of the trading day. The blocks in these profiles represented the generations as explained previously, but the profile of their quantities in each hour were

calculated in a way that made the shape fit over the initial profile. This was done to ensure the output continued correctly from the earlier profile.

Similarly, supplementary profiles which represented a unit being kept on were added after the initial shape. The blocks in these profiles represented the generations as explained previously, with quantities calculated in a way which allowed the shape fit over the initial shut down profile. These supplementary profiles did not represent staying on and then shutting down – they only represented staying on and did not contain a shutdown profile.

Figure 13 illustrates how the hourly quantity profile of the supplementary profile was calculated in a way which allows the shape to fit over the initial profile, for an example of supplementary profiles bringing a unit on earlier than its initial profile. The quantities in the Supplementary Profile Order (in red) are calculated as follows:

$$Q_{\text{SuppNew},l,h} = Q_{\text{Supp},l,h} - Q_{\text{Initial},l,h}$$

where $Q_{\text{Supp},h}$ is the original quantity in the hour of the layer block in the supplementary profile taken from the equivalent block in the initial profile but shifting the hour in which the profile starts to a number of hours earlier, $Q_{\text{Initial},h}$ is the quantity in the hour of the layer block in the initial profile, and $Q_{\text{SuppNew},h}$ represents the updated quantity in the hour of the layer block in the hatched area. In some cases the new quantity may be equal to zero, where the quantities in an hour of the initial profile and the shifted supplementary profile are equal.

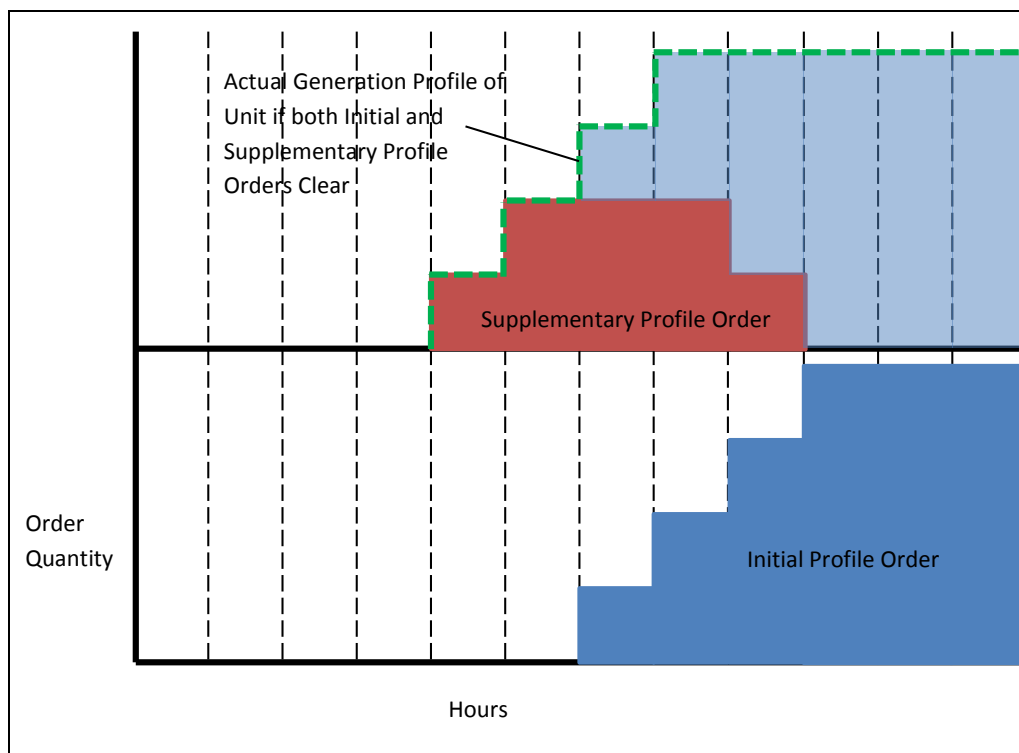


Figure 13 Illustrative example of fitting supplementary profile over initial profile

No-load costs for the overlap hours (the hatched hours in the illustration given) were not incorporated into the first layer block of the supplementary profile. This is because they have already been taken into account in the profile block over which this new block has been fit.

For units already on at the start of the trading day, the parent block was situated in the first hour of the trading day. Since there is no Min-On time requirement, the initial profile at the start of the day and supplementary profiles to keep the unit on thereafter were all given lengths of 4 hours.

The blocks used for each profile represented the generations as explained previously. For units on at their max capacity at the start of the trading day, none of the hourly quantity values in the blocks needed to be profiled as the previous block had them already at their desired output – constant values for quantity for each block were used in each hour. For units on at less than their max capacity, the initial profile at the start of the trading day required profiled values for the quantities in the blocks to ramp them up to max capacity, with constant values for quantity used in the supplementary profiles.

The same values were used for every set of blocks, with no ramp down or shut down profiles. The main reason for excluding ramping down and shutdown profiles in the supplementary blocks was to reduce the complexity of creating the orders. In general the ramping down and deloading rates for most units are much quicker than the ramping and loading up rates.

Although European market operators apply limits to the number of levels of blocks which can be used, no limits were assumed in this exercise. Ignoring these limits may result in a different level of performance of the algorithm than would happen if the market operator applied limits. A limit of one block being able to link down a generation to only one other block was assumed: i.e., a child could only link to one parent, but the parent could have multiple children linking to it. This is not a limit set by EUPHEMIA but was assumed for simplification in this exercise.

The relationships between the blocks in this exercise are illustrated in Figure 14 for units not already on at the start of the trading day, and in Figure 15 for units already on at the start of the trading day. All blocks depend on the Parent block clearing in order for them to clear. This guarantees that startup costs and min-on time must be respected for any orders to clear (except for units which were already on at the start of the trading day, where these did not need to be respected). All 1st Level blocks depend on what happened in the previous 1st Level block if keeping the unit on, or the next 1st Level block if bringing the unit on earlier, in order for them to clear. This guarantees that the unit can only be kept on for the following hours if it was on in the previous hours, or that the unit can only be brought on some hours earlier if it is cleared to be on in the following block of hours.

All levels of blocks depend on what is happening to the level below them, e.g. a unit can only be cleared to generate a quantity of Q_3 if the block bringing the quantity to Q_2 also clears for that interval. Since the start of these chains are the 1st level blocks, this guarantees that units cannot generate unless the fixed no-load costs for those hours are recovered and the MSG level of the unit is respected.

A simple rule of thumb can be used to explain the linking of blocks as per the assumptions made in this exercise: on the bottom layer, link towards the parent, and above the bottom layer, link downwards.



Figure 14 Illustrative example of the linking relationships between linked blocks for units not already on at the start of the trading day

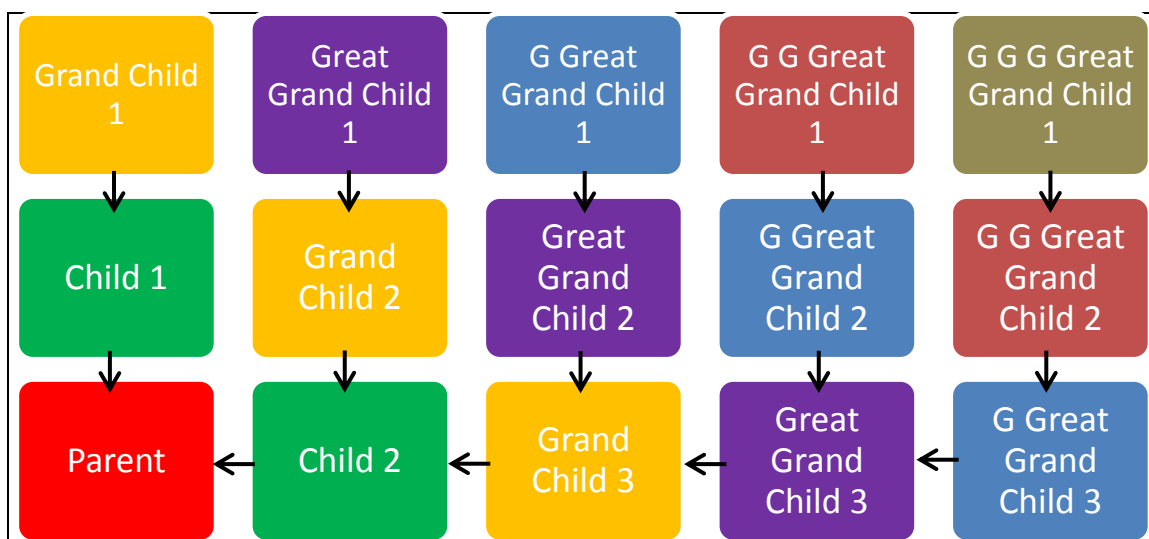


Figure 15 Illustrative example of the linking relationships between linked blocks for units already on at the start of the trading day

All linked blocks created using the methodologies outlined must have a MAR of 100%, i.e. the entire block must be accepted or rejected (“fill or kill”). This is because of the dependency between the blocks (i.e. block X must be fully accepted before block Y which depends on block X can be accepted).

Examples of how these orders were created in table format will be made available in a supplementary spreadsheet to this document.

7.3.3. COMPLEX ORDERS

The submission of PQ pairs in complex orders is similar to that for simple orders represented by a stepwise curve. However, this time it is possible to represent the entire spectrum of PQ pair submission included in the unit’s SEM COD, rather than just one PQ pair as shown previously. The same stepwise curve was included in each hour in order to represent the flexibility of the SEM to clear any quantity in an hour, while trying to use the other complex conditions to ensure the technical feasibility of those quantities.

For units which were already on, the curves in the first up-to three hours of the trading day were different to the rest of the hours to facilitate the Scheduled Stop condition. The quantities used for the curves in scheduled stop condition hours were taken from the ramping down and deloading profile of the units. The prices for these components of the curve were dependant on where the new quantity rested on the normal stepwise curve of PQ pairs. The other PQ values in these hours were adapted to suit these extra points on the curve.

The Minimum Income Condition (MIC) fixed term for units already on was calculated as the sum of a single instance of startup costs, and no-load costs for each of the 24 hours of the trading day, i.e. MIC Fixed Term = Startup Cost + (24 x No-Load Cost). The MIC fixed term for units already on did not need to include startup costs; therefore, it just consisted of a unit’s no-load costs over the 24 hours of the trading day. The assumption to include 24 hours of no-load cost may be taken to guarantee the recovery of all potential costs.

It was difficult to decide on how the variable MIC term should be calculated. Setting it to seemingly intuitive levels, such as the lowest of the prices in the PQ pairs submitted, could result in the generator being cleared and fulfilling the MIC but not actually earning enough from the market to cover all of its costs. The following example illustrates this point.

The formula governing the MIC is as follows:

$$T_f + T_v \cdot \left(\sum_h \sum_{o \in h} [g_o \cdot x_o] \right) \leq \sum_h \left(MCP_h \cdot \left(\sum_{o \in h} [g_o \cdot x_o] \right) \right)$$

Take an example unit, with the following COD:

- P_1 104.26 €/MWh, Q_1 120MW
- P_2 112.84 €/MWh, Q_2 190MW
- P_3 113.81 €/MWh, Q_3 258MW
- MIC fixed term $T_f = €183,550$ as a combination of its startup and no-load costs over 24 hours.

Assume the MIC variable term is equal to the lowest price of the PQ pairs submitted ($T_v = 104.26$ €/MWh), and that the unit clears at its max capacity, Q_3 in every hour of the trading day, with a market clearing price greater than the highest price it included in its PQ pairs (MCP = 135 €/MWh). Using the MIC equation and the data assumed, the following can be calculated, with the left side of the equation being the MIC calculation, and the right side of the equation being the amount actually earned from the market:

$$183550 + 104.26(258 \times 24) \leq 135(258 \times 24)$$

$$829127.9 \leq 835920$$

Therefore, it is true that the amount earned from the market is greater than the MIC and the order clears.

However, the actual costs to the generator are as follows:

$$24. [(P_1 \cdot Q_1) + (P_2 \cdot (Q_2 - Q_1)) + (P_3 \cdot (Q_3 - Q_2))] + T_f$$

$$24. [(104.26 \times 120) + (112.84 \times (190 - 120)) + (113.81 \times (258 - 190))] + 183550$$

$$= 859127.9$$

Comparing this with the amount earned from the market, the actual cost of generating to meet the cleared order is greater than the amount earned in the market ($835920 < 859127.9$), despite respecting the MIC component of the order. With a similar example, it can be shown that if the variable term is made equal to the largest price of the PQ pairs submitted, the opposite could occur: the unit's MIC may not be satisfied even if the amount earned in the market covers all of the unit's costs of generation. This excludes two of the intuitive options for determining the variable term of the MIC.

As a result of this, the following solution was used: a weighted average of the prices submitted by the unit in its COD. The prices were weighted by the quantity they were paired with in order to create each unit's MIC variable term. A single figure per unit per day was submitted for the fixed and variable terms of the MIC.

Similar difficulty was found with representing the ramping rates of the unit in its Increase and Decrease Gradient conditions. Only one figure can be submitted per unit per trading

day for each of these conditions, while at the moment in the SEM up to 5 ramping up rates, up to 5 ramping down rates (loading and deloading rates are not explicitly modelled in the MSP software).

For this exercise the Increase and Decrease Gradient condition values were calculated as the quantity weighted average of the ramp rates from the TOD submitted by each unit in the SEM, with the quantity taken as the difference between the two ramp quantities between which the ramp rate operates.

Figure 16 shows an example of the completed complex order structure for a unit starting, and Figure 17 shows this for a unit already on with an additional scheduled stop condition.

Portfolio	Date	Block No.	Position	Price	MIC Fixed Term (€)	MIC Variable Term (€/MWh)	Increase Gradient	Decrease Gradient	Scheduled Stop Periods	01	02	03	04	05				
104	03/03/2014	1	1	104.26	183550	109.10	251.5	251.5	0	0	0	0	0	0				
104	03/03/2014	1	2	104.26	183550	109.10	251.5	251.5	0	-36	-36	-36	-36	-36				
104	03/03/2014	2	3	104.26	183550	109.10	251.5	251.5	0	-36.1	-36.1	-36.1	-36.1	-36.1				
104	03/03/2014	2	4	104.26	183550	109.10	251.5	251.5	0	-120	-120	-120	-120	-120				
104	03/03/2014	3	5	112.84	183550	109.10	251.5	251.5	0	-120.1	-120.1	-120.1	-120.1	-120.1				
104	03/03/2014	3	6	112.84	183550	109.10	251.5	251.5	0	-190	-190	-190	-190	-190				
104	03/03/2014	4	7	113.81	183550	109.10	251.5	251.5	0	-190.1	-190.1	-190.1	-190.1	-190.1				
104	03/03/2014	4	8	113.81	183550	109.10	251.5	251.5	0	-258	-258	-258	-258	-258				
06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36	-36
-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1	-36.1
-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120
-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1	-120.1
-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190	-190
-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1	-190.1
-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258	-258

Figure 16 Non-peaker thermal unit not already on at start of trading day complex orders

Portfolio	Date	Block No.	Position	Price	MIC Fixed Term (€)	MIC Variable Term (€/MWh)	Increase Gradient (MW/h)	Decrease Gradient (MW/h)	Scheduled Stop Periods	01	02	03	04	05				
144	03/03/2014	1	1	18.72	80424	22.46	600.0	540.0	1	0	0	0	0	0				
144	03/03/2014	1	2	18.72	80424	22.46	600.0	540.0	1	-158.9	-207	-207	-207	-207				
144	03/03/2014 (2)	(3)		18.72	80424	22.46	600.0	540.0	1	-159								
144	03/03/2014 (2)	(4)		18.72	80424	22.46	600.0	540.0	1	-207								
144	03/03/2014	2	3	26.23	80424	22.46	600.0	540.0	1	-207.1	-207.1	-207.1	-207.1	-207.1				
144	03/03/2014	2	4	26.23	80424	22.46	600.0	540.0	1	-405	-405	-405	-405	-405				
144	03/03/2014	3	5	26.24	80424	22.46	600.0	540.0	1	-405.1	-405.1	-405.1	-405.1	-405.1				
144	03/03/2014	3	6	26.24	80424	22.46	600.0	540.0	1	-412	-412	-412	-412	-412				
06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207	-207
-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1	-207.1
-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405	-405
-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1	-405.1
-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412	-412

Figure 17 Non-peaker thermal unit already on at start of trading day complex orders (Scheduled Stop Condition additional points on the curve in grey rows)

7.3.4. EXCLUSIVE GROUP BLOCK ORDERS

Exclusive group block order cases were the most time and effort intensive of all the types of EUPHEMIA orders to create. It involved a large number of combinations and permutations of generating profiles depending on the initial conditions of the unit and the length of the

ramping/loading profiles. The profiles created were assumed to be the subset of all possible profiles which most thoroughly represent the possible options for what the SEM could schedule, while most accurately reflecting the desired generating behaviour and goals of participants in the market. All profiles are contained in a single block, with a single price.

For units not already on, the following profiles were created:

1. A profile starting the unit and moving to max output, keeping it on at max output for at least min on time, then bringing unit off. This is then copied to create additional profiles which shift the start and end times to later hours, starting from 23:00hrs and shifting to 00:00, 01:00, 02:00, etc., until a profile where the last quantity of the profile is in the last hour of the trading day.
2. Taking initial profile from Point 1, and extending time kept on at max output by one hour. This is then copied to create additional profiles which shift the start and end times to later hours, starting from 23:00hrs and shifting to 00:00, 01:00, 02:00, etc. This is done until a profile where the last quantity of the profile is in the last hour of the trading day.
3. Point 2 is repeated, each time extending the time kept on at max output by an extra hour, copying to create profiles starting and ending in different hours. This is done until a profile is created which has its first quantity at the start of the trading day and its last quantity at the end of the trading day.
4. A profile starting at 23:00, bringing the unit on the max output and keeping it on there until the end of the trading day at 23:00. This is then copied to start in each following hour (00:00, 01:00, 02:00, etc., with no output in the previous hours), each time keeping the unit on at max until the end of the trading day, reducing by an hour each time the amount of time it is kept at max. This is done until the final profile is created, which has the unit being kept on at its max output for its min-on time at the end of the trading day.

For units whose initial conditions had them already on at their max availability at the start of the trading day, the following profiles were created:

1. A profile keeping the unit on at its max availability for the 24 hours of the trading day.
2. A profile keeping the unit on at its max availability until the hour it needs to start ramping down in order to have the last quantity of its ramping down profile in the last hour of the trading day.
3. Point 2 is repeated, each time having the unit start ramping down to 0 an hour earlier, i.e. reducing the amount of time the unit is on at max by an hour each time. This is done until a profile is created where the quantity in the first hour of the trading day max output, and the quantity in the second hour is the start of the unit's ramping down profile.

4. The final profile is the unit's ramping down profile beginning in the first hour of the trading day.

For units whose initial conditions had them already on at less than their max availability at the start of the trading day, the following profiles were created:

1. A profile having the unit ramping up from its initial position to its max output from the first hour of the trading day, and staying on at its max output for the rest of the trading day.
2. Taking the initial profile from Point 1, copying but having the unit ramp up from its initial position an hour later each time (i.e. Point 1 had its ramp up profile begin in hour 23:00, these would have it start in hour 00:00, 01:00, 02:00, etc.). This requires the hours preceding the start of the ramp up profile to have a quantity equal to the initial output condition of the unit. This is done until a profile is created where the quantity in last hour of the trading day is that of the beginning of the unit's ramping up profile.
3. A profile keeping the unit on at its initial output position for the 24 hours of the trading day.
4. Copy all profiles created in Points 1 and 2, and make adjustments to keep the unit on at its max availability until the hour it needs to start ramping down from max in order to have the final quantity of its ramping down profile in the last hour of the trading day. For some units, e.g. those with ramp down profiles over two hours, this adjustment can result in duplication of profiles – delete duplicates to leave only one of each profile type.

Where the quantity in the hour before the ramping down profile begins is the initial output position of the unit, change the ramping down profile from the ramping-down-from-max profile to the ramping-down-from-initial-position profile.

This group of profiles means that the unit can ramp up from its initial position in any hour, and ramp down at the end of the day.

5. Copy the profiles created in Point 4, having the unit's ramping down profile start an hour earlier each time. These profiles result in time at max being an hour less each time, meaning ramping down starts an hour earlier and the time at 0 output at the end of the day increases by an hour each time.

This group of profiles means that the unit can ramp up from its initial position in any hour, and ramp down in any hour, meaning all combinations of ramping up to max and ramping down to 0 are covered.

This is repeated until a profile is created which has only the initial output position followed by the ramping down profile from the initial position for that unit.

6. The final profile is the unit's ramping down from initial position profile starting in the first hour of the trading day.

As previously explained, blocks which are “fill-or-kill” cannot be used to set the price in the market.

European market operators set a limit on the number of groups allowed per unit and number of blocks allowed per group (for example, EPEX Spot sets a limit of 3 groups per portfolio, 8 blocks per group), but no limit was set in their use for this exercise. In order to try and best represent the SEM, all permutations of what participants would want to do and could technically do were made into individual profiles included in a single group. This resulted in a very large number of permutations being required: for some units, over 300 profile blocks were created for a single exclusive group.

Examples of the exclusive group orders are included in the supplementary documents published with this document.

7.4. CREATION OF ORDERS – PUMPED STORAGE UNITS

It was not immediately apparent which type of EUPHEMIA order would be most suitable for pumped storage hydro units, given that each offered different advantages and disadvantages over the others. The following outlines the initial thinking during the preliminary examination of the orders types:

- Simple Orders:
 - Two options for reflecting running behaviour were explored. The first would be a pumping profile for night time and generating profile for peak time hours. The second would be a simultaneous bid to buy below a certain price and an offer to sell above a certain price in every hour with a deadband reflecting the cycle efficiency of the unit and the price zone in which they would not be willing to participate.
 - Could have partial clearing in an hour, which offers flexibility in what volume can be cleared, and in which hours it can be cleared.
 - Offers flexibility for units to set the price.
 - Allows each hour to be considered independently. This means that possible cascade effects of one hour failing clear affecting other hours as with linked block orders can be avoided.
 - Could result in orders clearing in a way which could cause the reservoir to breach its maximum or minimum limits.
- Complex Orders:
 - Could have partial clearing in an hour, which offers flexibility in what volume can be cleared, and in which hours it can be cleared.
 - Could result in orders clearing in a way which could cause the reservoir to breach its maximum or minimum limits.
 - Offers flexibility for units to set the price.

- Allows each hour to be considered independently (with the exception of the ramp condition rule) avoiding cascade effects that occur with linked blocks.
- MIC, ramp rates and scheduled stop functions wouldn't be useful; therefore, the complex orders don't appear to offer any advantages over simple orders.
- Exclusive Group Block Orders:
 - If one block was used for both pumping and generating, it would be possible to guarantee that the units couldn't generate more than stored and reservoir levels could be safely managed. This also retains some flexibility, as different blocks in one group give choice over which hours the order can clear.
 - However if one block was used, it wouldn't be possible to use a min acceptance ratio of less than 100%, meaning the unit wouldn't have the flexibility over the MW quantity to clear in a block. This is because of having both negative and positive values in one block. This also adds complexity to the formulation of the price for the block, as a single price would be used for both buying and selling. The flexibility over the MW quantity to clear could be retained by adding extra blocks to the group with different quantity profiles, but this would add significantly to the number of permutations of profiles the unit could submit.
 - If two or more exclusive groups were used, one for blocks of pumping and another for blocks of generating, a MAR of less than 100% could be used to have flexibility in what quantity can be cleared. However this could result in a situation where generating blocks clear and pumping blocks don't clear, making reservoir level management less secure.
 - Where a MAR of 100% must be used, this prevents the units from being able to set the price.
- Flexi Orders
 - Could have a either a pumping block for night time or a generating block for peak time, and only of one hour length. This could only be useful in situations where for example the unit has a reservoir level above their target reservoir level for the end of the day and if generating at a certain MW level for one hour could bring them down to the target, or if a unit is below their target level and if pumping at a certain level MW level could bring them up to the target.
 - Flexibility is retained in which hours could have cleared orders, but not in the MW quantity which can be cleared: all of block has to be accepted, and min acceptance ratio cannot be below 100%.
 - Reservoir level management may be easier, but at the cost of not being able to buy and sell in the same day.
- Linked Block Orders
 - Could have parent pumping block linked to child generating block. This would mean the unit would only generate what it has stored.

- There would be no flexibility in which hours could have cleared orders, but flexibility can be retained in the amounts cleared through using different blocks with different prices for different generation/pumping levels.
- The “Fill or Kill” aspect of the blocks prevents the units from being able to set the price.
- With min acceptance ratio of 100%, the unit is guaranteed not to generate more than they have stored, but this reduces flexibility as the entire quantity of the blocks must be accepted. Using a MAR of less than 100% for generation blocks where possible would allow flexibility in what could be generated without risking that the unit could be cleared to generate more than stored.

Following a review of the approaches, for this work the following were selected:

- Linked block orders were one chosen as they offer some flexibility in terms of the amounts which can be cleared, while guaranteeing that the unit can safely manage its reservoir levels.
- Simple orders were also chosen as they allow for the unit to be declared available for both buying and selling at the same time depending on the market price, but requiring the assumption that pumped storage units would not take their reservoir levels into account in their DAM submissions.

7.4.1. LINKED BLOCK ORDERS

For the linked block orders, two different scenarios were explored – “Buy and Sell” Linked Blocks, and “Extended” Linked Blocks.

For the Buy and Sell Linked Block scenario, each pumped storage unit was assumed to have the following goals in the market:

- The unit would want to pump at night/early evening when electricity is cheaper, generate near peak time when more expensive. The prices for each of these activities were estimated based on assumed desired price deadbands of €20/MWh for arbitrage. The following price levels were included in these orders:
 - If the price is below €40/MWh, the unit should try to pump to bring reservoir level up to target level
 - If the price goes below an even lower level (€20/MWh) and the unit was able to bring reservoir level up to target level, it should try to pump to bring reservoir level up to its maximum level
 - If the price goes above €60/MWh, and the reservoir level is sufficient, then it should try to generate to bring reservoir level down to its previous level

- If the price goes above an even higher level (€80/MWh) and the reservoir level is sufficient, it should try to generate to bring the reservoir level down to its target level
- If the price goes above an even higher level (€100/MWh), the unit should try to generate to bring the reservoir level from its previous level to its min level.

Different blocks were used to offer flexibility in pumping and generating, with the goal of these blocks being to change the reservoir level from one point to another (e.g. from its level at the start of the day to its target level for the end of the day). Calculating block profiles was carried out in the following order, with the following checks, and the following prices and generation levels associated with those blocks:

- Pumping up from previous level to target reservoir level
 - Check if Target Level is greater than previous level. If no, then quantity here is zero. If yes, then the quantity in that hour of the block is the minimum of the target reservoir level minus the previous reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max pumping load capacity.
 - Repeat for following hour(s) until the quantity result is less than the max pumping load capacity.
- Pumping up from target reservoir level to max reservoir level
 - Check if Target Level is greater than previous level. If no, then quantity in that block in that hour is the minimum of the max reservoir level minus the previous reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max pumping load capacity minus any quantity already present in that hour from another block. If yes, then the quantity in that block in that hour is the minimum of the max reservoir level minus the target reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max pumping load capacity minus any quantity already present in that hour from another block.
 - Repeat for following hour(s) until the quantity result is less than the max pumping load capacity.
- Generating down from target reservoir level to previous reservoir level
 - Check if target level is greater than previous level. If not, then the quantity in this hour is 0. If it is, the quantity in that hour is the minimum of the target reservoir level minus the previous reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max generating capacity.
 - Repeat for following hour(s) until the quantity result is less than the max generating capacity.
- Generating down from max reservoir level to target reservoir level

- Quantity in an hour is the minimum of the maximum reservoir level minus the target reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max generating capacity minus the current hour's generation from other blocks (i.e. the generation from target to previous reservoir levels). This block does not need a check as to whether the target reservoir level is greater than the previous reservoir level, as this is already considered in the previous generating block: if the target level is less than the previous level, the previous generation block will have a quantity of 0, and this block will consider all of the generation required to the lower target level.
- Repeat for following hours until the quantity result is less than the max generating capacity minus the generation in that hour from other blocks.
- Generating down from previous reservoir level to minimum reservoir level
 - This is likely to be the largest block, taking multiple hours to fulfil the generation required. The first step is to check if the target reservoir level is greater than the previous reservoir level. If it is, then the quantity in an hour is the minimum of the previous reservoir level minus the minimum reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max generating capacity minus the current hour's generation from other blocks (i.e. the generation from max to target reservoir levels, and target to previous reservoir levels). If it isn't, then the quantity in an hour is the minimum of the target reservoir level minus the minimum reservoir level (divided by four to account for this one unit's contribution to the whole reservoir), or the max generating capacity minus the current hour's generation from other blocks (i.e. the generation from max to target reservoir levels, and target to previous reservoir levels).
 - Repeat for following hours, each time taking into account the generation from the previous hour of the block, i.e. the quantity in the following hours becomes the minimum of the previous reservoir level minus the minimum reservoir level (divided by four to account for this one unit's contribution to the whole reservoir) minus the generation in the previous hours of this block, or the max generating capacity minus the current hour's generation from other blocks (i.e. the generation from max to target reservoir levels, and target to previous reservoir levels). This is similarly applied to the situation when the target reservoir level is less than the previous reservoir level. Repeat this until the quantity result is less than the max generation capacity minus the generation in that hour from other blocks.

This was done for all four pumped storage units, each only influencing a quarter of the reservoir level. In order to build in added flexibility for the hours in which the pumped

storage orders could clear in the market (both in generation and consumption), each of the four units were given a different starting hour for their parent blocks.

Figure 19 and Figure 20 below illustrate the workings of the calculation for pumped storage unit blocks under the Buy and Sell Linked Blocks scenario, highlighting the effects of the blocks on the reservoir level, and the links between bids (which blocks must first be cleared by the algorithm to allow another block to be cleared).

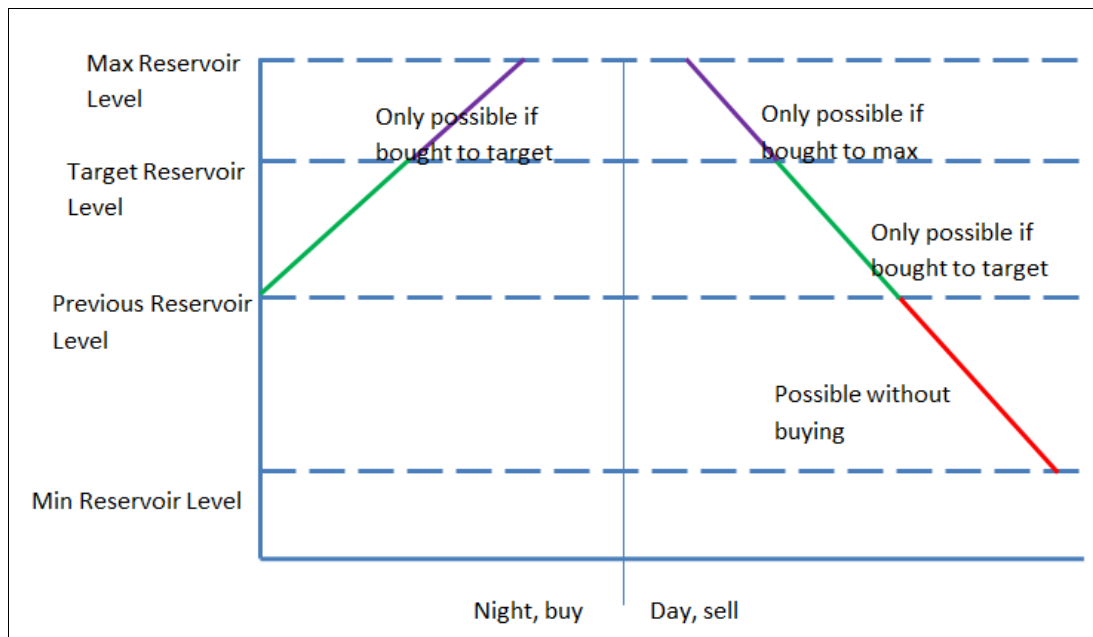


Figure 19 - Illustrative example of Buy and Sell Linked Blocks Scenario effects and relationship of blocks with reservoir levels

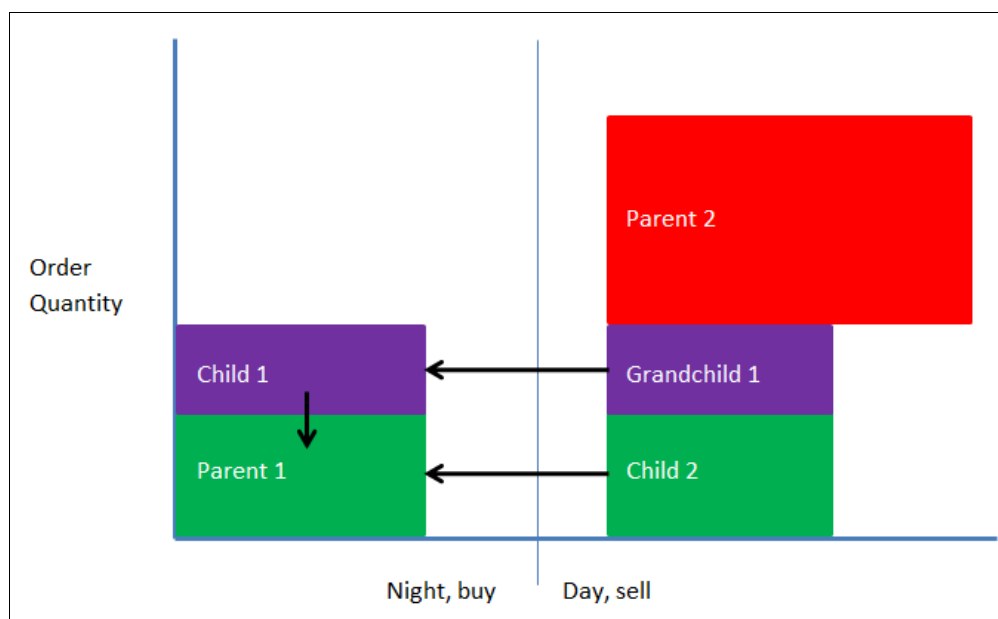


Figure 20 - Illustrative example of Buy and Sell Linked Blocks Scenario links and relationships between blocks

Figure 21 shows an example of how these orders were created in table format.

Anon Portfolio	Date	Order Ref	User Ref	Block Period	GMT/BST	Price	Volume	Min Accept MW	Min Accept %	Linked To	Order Type	BuySell	01	02	03	04	05
165	23/03/2014	P1	Up from Prev to Target	B01	23:00-00:00	40			100		C02	B	43				
165	23/03/2014	C1	Up from Target to Max	B01	23:00-00:00	20			100	P1	C02	B	12.5				
165	23/03/2014	C2	Down from Target to Prev	B14	12:00-13:00	60			0	P1	C02	S					
165	23/03/2014	GC1	Down from Max to Target	B14	12:00-13:00	80			0	C1	C02	S					
165	23/03/2014	P2	Down from Prev to Min	B1417	12:00-16:00	100			0		C02	S					
164	23/03/2014	P1	Up from Prev to Target	B02	00:00-01:00	40			100		C02	B	43				
164	23/03/2014	C1	Up from Target to Max	B02	00:00-01:00	20			100	P1	C02	B	12.5				
164	23/03/2014	C2	Down from Target to Prev	B15	13:00-14:00	60			0	P1	C02	S					
164	23/03/2014	GC1	Down from Max to Target	B15	13:00-14:00	80			0	C1	C02	S					
164	23/03/2014	P2	Down from Prev to Min	B1518	13:00-17:00	100			0		C02	S					
167	23/03/2014	P1	Up from Prev to Target	B03	01:00-02:00	40			100		C02	B	43				
167	23/03/2014	C1	Up from Target to Max	B03	01:00-02:00	20			100	P1	C02	B	12.5				
167	23/03/2014	C2	Down from Target to Prev	B12	10:00-11:00	60			0	P1	C02	S					
167	23/03/2014	GC1	Down from Max to Target	B12	10:00-11:00	80			0	C1	C02	S					
167	23/03/2014	P2	Down from Prev to Min	B1215	10:00-14:00	100			0		C02	S					
166	23/03/2014	P1	Up from Prev to Target	B04	02:00-03:00	40			100		C02	B	43				
166	23/03/2014	C1	Up from Target to Max	B04	02:00-03:00	20			100	P1	C02	B	12.5				
166	23/03/2014	C2	Down from Target to Prev	B11	09:00-10:00	60			0	P1	C02	S					
166	23/03/2014	GC1	Down from Max to Target	B11	09:00-10:00	80			0	C1	C02	S					
166	23/03/2014	P2	Down from Prev to Min	B1114	09:00-13:00	100			0		C02	S					

06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
									-43									
									-12.5									
									-23.5	-79	-79	-73						
									-43									
									-12.5									
									-23.5	-79	-79	-73						
									-43									
									-12.5									
									-23.5	-79	-79	-73						
									-43									
									-12.5									
									-23.5	-79	-79	-73						

Figure 21 Pumped storage hydro unit linked block orders for Buy and Sell Linked Blocks Scenario

For the Extended Linked Blocks, each unit was assumed to have the following goals in the market:

- Each would want to continuously cycle between buying and selling, rather than only taking each action once a day. They would wish to buy in the early morning, sell in the later morning, buy in the afternoon, sell in the evening, and buy again at night to get back to their target level. This means that buying and selling orders are situated approximately at the times most suitable for them to clear in the market, while allowing continuous cycling between buying and selling. Similar dependencies to the previous linked block case were included, for example a unit would only be able to sell a quantity which brings its reservoir level from the max level to the target level if they have bought to pump their reservoir level up to max in the previous pumping cycle.
 - o Two prices are used: a price below which they are willing to buy, and a price above which they are willing to sell, with a deadband in between based on the unit's cycle efficiency. The price below which the unit would be willing to buy was estimated from actual SMP on the trading days used.

This scenario required cycles of buying and selling to occur with small breaks (1-2 hours) throughout the day, using the same types of blocks as indicated for the Buy and Sell Linked Blocks scenario, with a number of changes:

- Generating down to, or pumping back up to, previous reservoir level is not considered after the use of this reservoir level in the set of blocks at the very start of the day. From then on there were only references to max, min and target reservoir levels. The placement of these blocks also wasn't staggered as done previously.
- The prices were based on an analysis of the actual SMP on the days in question, and the price spread was based on the cycle of efficiency of the units. This is an improvement on the more ad-hoc approach to the previous blocks. This meant that prices for different buy blocks were the same (and similarly the same prices for different sell blocks), rather than the approach used in the Buy and Sell Linked Block scenario.

The Extended Linked Blocks scenario was created to try and improve on three of the shortcomings of the Buy and Sell Linked Blocks scenario:

- o To reflect more accurately the availability of the unit over the day;
- o To allow the possibility of having all four units generating or pumping at the same time; and
- o To have more realistic prices in the orders.

One potential shortcoming remains with this approach, in that there is a cascade effect. If an order earlier in the day fails to clear in the market, it could result in all subsequent orders failing to clear. Figure 22 illustrates how the blocks are related, while Figure 23 shows an example of how these orders were created in table format.

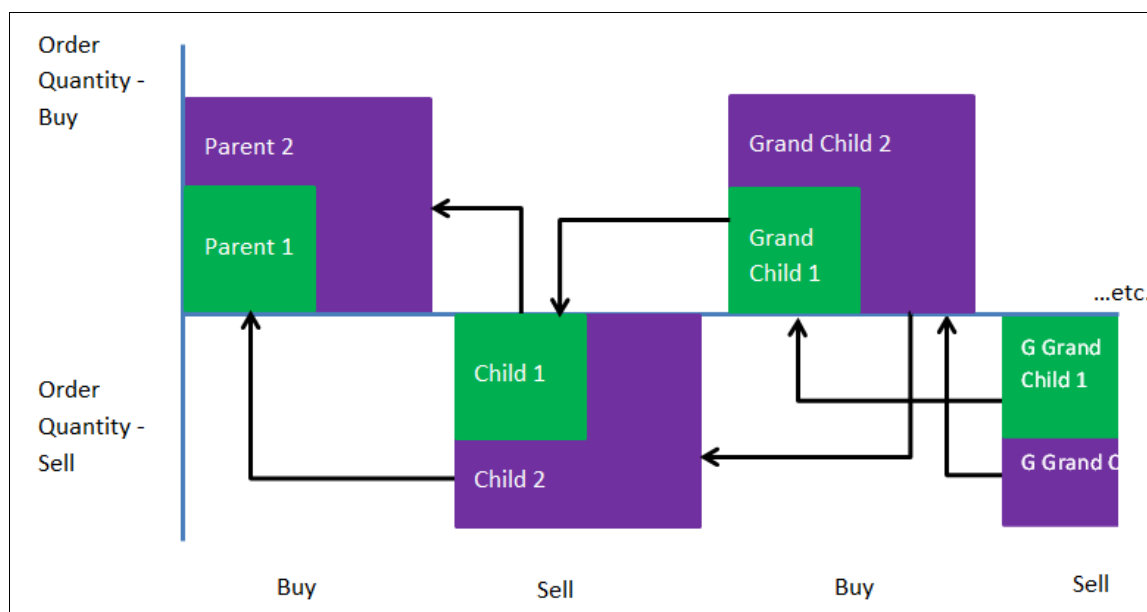


Figure 22 Illustrative example of Extended Linked Blocks Scenario links and relationships between blocks

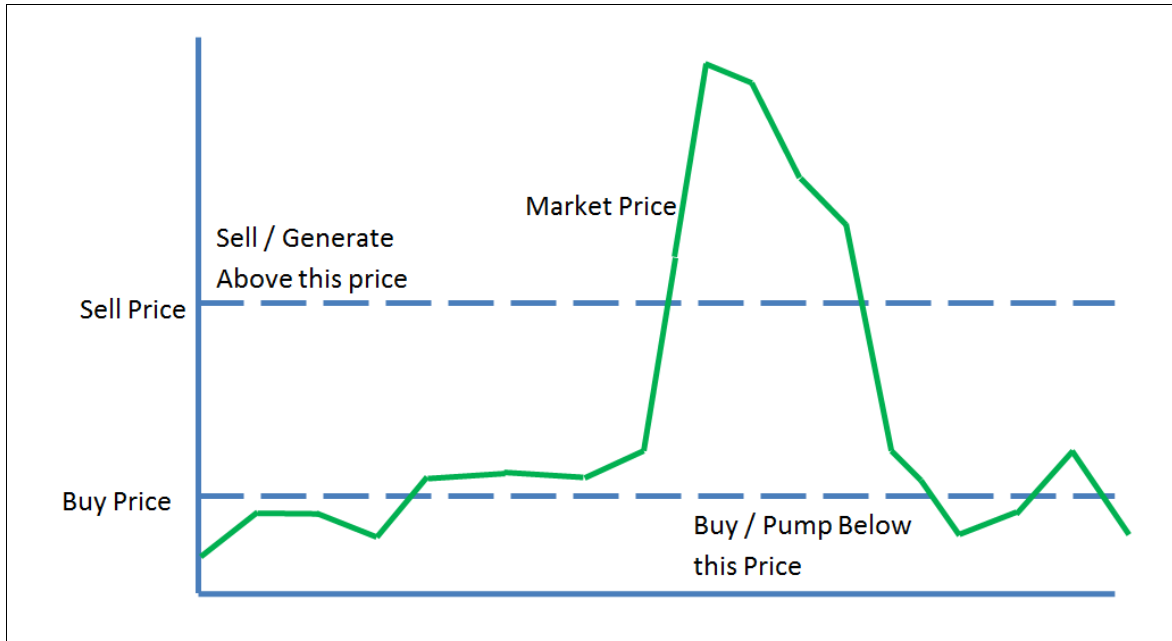


Figure 24 Illustration of pumped storage unit simple orders interactions with the market price

Portfolio	Market Day	Period	GMT/BST	-500	44	44.1	62.9	63	3000
165	03/03/2014	01	23:00-00:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	02	00:00-01:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	03	01:00-02:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	04	02:00-03:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	05	03:00-04:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	06	04:00-05:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	07	05:00-06:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	08	06:00-07:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	09	07:00-08:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	10	08:00-09:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	11	09:00-10:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	12	10:00-11:00	71.9	71.9	0	0	-79	-79
165	03/03/2014	13	11:00-12:00	71.9	71.9	0	0	-79	-79

Figure 25 Pumped storage hydro unit simple block orders for Simple Order Scenario