TRILATERAL MARKET COUPLING

ALGORITHM APPENDIX

September 2006

Table of contents

1 Definitions and Abbreviations

For the purpose of this Trilateral Market Coupling Algorithm Appendix the definitions of the Market Rules and the Functional Procedure shall apply to capitalized terms and expressions. In addition the definitions set out hereunder apply to capitalized terms and expressions.

This document has been elaborated in common by APX, Belpex and Powernext SA and shall be implemented by them in view of market coupling between the power exchanges they each operate. As a result certain terms and definitions used in this document may differ from the terms and definitions used in the APX Rules and Regulations DAM. In case of contradiction in terms, this Trilateral Market Coupling Algorithm Appendix will prevail over the terms and definitions being used in the APX Rules and Regulations DAM.

ATC: Available Transfer Capacity;

$ATC_{x,y,h}$: ATC from Market *X* to Market *Y* for Settlement Period *h* of the following Day, as defined daily by the TSOs prior to the Market Coupling matching. For each interconnection involved in the Market Coupling, an ATC is defined for each Settlement Period and in each direction;

Bid: a Block Bid or a Divisible Hourly Bid;

Block Bid: a Block Order for the purchase of electricity;

Block Offer: a Block Order for the sale of electricity;

Block Order: an Order on a product comprising of one or several consecutive Settlement Periods, that can either be executed for its entire quantity and over all Settlement Periods or not be executed at all; the Price Limit of a Block Order has to be compared with the average of MCPs over the corresponding Settlement Periods;

Divisible Hourly Bid: a Divisible Hourly Order for the purchase of electricity;

Divisible Hourly Offer: a Divisible Hourly Order for the sale of electricity;

Divisible Hourly Order: an Order on a product defined by one Settlement Period, and that is not a Block Order; an Order is defined by a product, a Price Limit, a quantity and a direction (purchase or sale);

High Level Properties (HLP): the set of properties that are met by the Market Coupling results;

Hub: A bilateral market platform in a country where electricity is exchanged between the balance perimeters of market actors;

Market Coupling: a decentralised coordinated day-ahead international congestion management mechanism by which the market prices and schedules of the day-ahead markets operated by the power exchanges of two or more neighbouring Hubs are simultaneously determined together with the use of the daily ATC.

$MCP_{X,h}$: MCP of market X for Settlement Period h;

$MCV_{X,h}$: Market Clearing Volume of market X for Settlement Period h;

$NBV_{X,h,k}$: Net Block Volume is equal to the (accepted) sale block volume minus the (accepted) purchase block volume of market X for Settlement Period h and iteration k;

NEC: Net Export Curve;

$NEC_{X,h,k}$: NEC of market X for Settlement Period *h* and iteration *k*, see section 4;

Net Position $E_{X,h}$: for each TSO X and each Settlement Period h, the TSO Net Position; the Net Position $E_{X,h}$ is equal to the Net Position $Q_{X,h}$ of the corresponding power exchange, within a margin allowing for rounding;

Offer: a Block Offer or a Divisible Hourly Offer;

PRB: Paradoxically Rejected Block; i.e. a Block Order that is rejected even though its price is compatible with the average of the MCPs of the relevant Settlement Periods;

Price Limit: the Price Limit is the submission price of an Order;

$Q_{X,h}$: Net Position (positive = export, negative = import) of market X for Settlement Period h;

Q*: the volume on a horizontal segment of a NEC representing the maximum volume of trade at that price in the local market;

Settlement Period: one hour;

Trilateral Market Coupling Algorithm: the algorithm described in this document;

TSO: transmission system operator, i.e. Elia System Operator SA/NV, RTE SA and/or TenneT TSO B.V. as the case may be;

TSO Net Position: the net quantity of electricity bought or sold by the TSO as a result of the matching on the power exchange operating in its Hub;

Winning Subset: the subset of the set of Block Orders in a market which are accepted at a given iteration.

2 Introduction

Market Coupling is both a mechanism for matching Orders on a power exchange and an implicit cross-border capacity allocation mechanism. Market Coupling improves the economic surplus of the coupled markets: the highest Bids and the lowest Offers of the coupled power exchanges are matched, regardless of the area where they have been submitted; matching results depend however on the ATC between the coupled hubs.

Market prices and schedules of the day-ahead power exchanges of the several connected markets are simultaneously determined with the use of the ATC defined by the relevant Transmission System Operators (TSOs). The transmission capacity is thereby implicitly auctioned and the implicit cost of the transmission capacity from one market to the other is the price difference between the two markets. In particular, if the transmission capacity between two markets is not fully used, there is no price difference between the markets and the implicit cost of the transmission capacity is null.

Basics of Market Coupling

This section is meant to give a qualitative explanation of Market Coupling.

Market Coupling relies on the principle that the market with the lowest price exports electricity to the market with the highest price. Two situations may appear: either the ATC is large enough and the prices of both markets are equalized (price convergence), or the ATC is too small and the prices cannot be equalized. These two cases are described in the following examples.

Suppose that, initially, the price of market A is lower than the price of market B. Market A will therefore export to market B, thus the price of market A will increase whereas the price of market B decreases. If the ATC from market A to market B is sufficiently large, a common price in the two markets may be reached, so that no market tends to export/import to the other anymore.

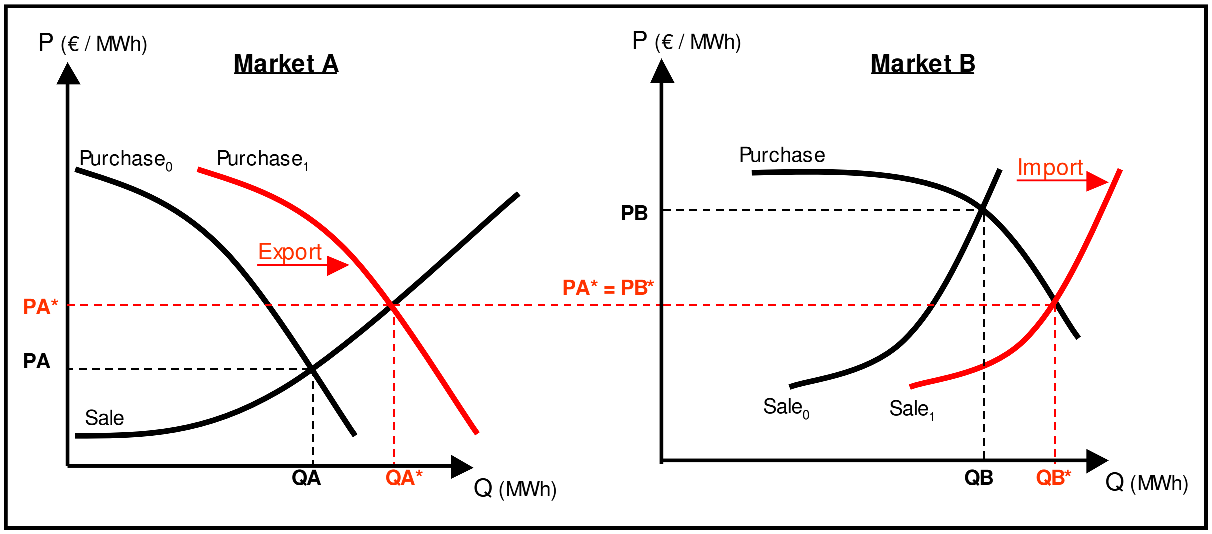
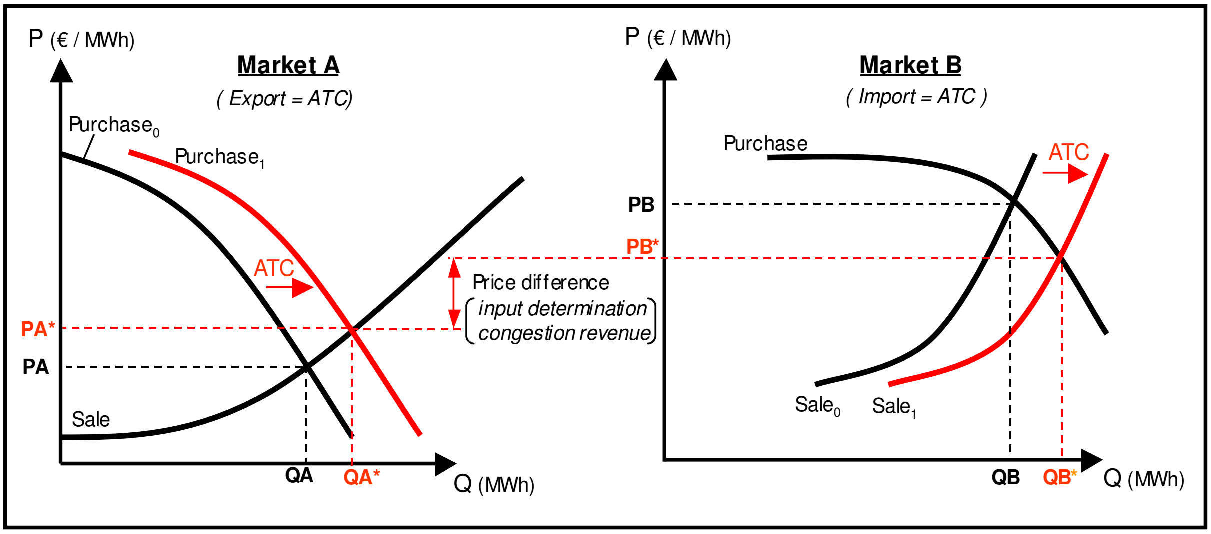


Figure 1- Representation of Market Coupling for two markets, no ATC congestion.

Another situation happens when the ATC is not sufficient to ensure price harmonization between the two markets. The amount of electricity exchanged between the two countries is then equal to the ATC and the prices are given by the intersection of the purchase and sale curves. Exported electricity is bought in the export area at a price of P_A*, and is sold in the import area at a price of P_B*. The difference between the two prices multiplied by the exchanged volume —i.e. ATC— is called congestion revenue, and is collected and used pursuant to article 6.6 of the Regulation (EC) N°1228/2003 of the European Parliament and of the Council of 26 June 2003 on condition for access to the network for cross-border exchanges in electricity.

Figure 2- Representation of Market Coupling for two markets, ATC congestion



3 Purpose of the Trilateral Market Coupling Algorithm

3.1 Input of the Trilateral Market Coupling Algorithm

The Trilateral Market Coupling Algorithm takes as an input:

- The ATC between each area for each flow direction and each Settlement Period of the following Day —i.e. for each hour of the following Day;
- The (Block Free) NECs of each market for each Settlement Period of the following Day, i.e. the difference between the total quantity of Divisible Hourly Bids and the total quantity of Divisible Hourly Offers for each price level (see section 4). The NEC reflects a market's import or export volume sensitivity to price;
- The Block Orders submitted by the participants in each local market.

3.2 Output of the Trilateral Market Coupling Algorithm

The Trilateral Market Coupling Algorithm provides as an output for each market:

- The set of accepted Block Orders;
- The Net Position for each Settlement Period of the following Day;
- The price (MCP) for each Settlement Period of the following Day.

3.3 High Level Properties

The results of the Trilateral Market Coupling Algorithm are consistent with a number of 'High Level Properties'. The High Level Properties can be divided into two subsets: (1) Market Coupling High Level Properties, and (2) power exchanges High Level Properties.

3.3.1 Market Coupling High Level Properties

The Market Coupling High Level Properties are constraints that the Market Results fulfil for each Settlement Period.

3.3.1.1 Description

	Constraint	Relevance
HLP1	MCP's are positive;	*Negative market prices are currently not permitted on any* power *exchange;*
HLP2	The absolute value of the sum of the TSO Net Positions is smaller than or equal to 1 MW;	*The TLC-calculated electricity exchanges between the individual hubs must be in balance. The TSOs in aggregate should not be net buyers or sellers (with a small tolerance to allow, inter alia, for rounding issues);*
HLP3	Every export or import schedule resulting from the TSO Net Positions is smaller than or equal to the ATC on the relevant interconnection in the relevant direction;	*The TLC-calculated electricity exchanges should be consistent with the published ATCs*
HLP4	The MCP at the importing side of an interconnection is not smaller than the MCP at the exporting side minus	*The TLC-calculated electricity exchanges should flow from the low-price market to the high price market (with a small tolerance to allow, inter*

	€ 0,10;	*alia, for rounding issues);*
HLP5	Whenever the export or import schedule resulting from the TSO Net Positions is smaller than the ATC on the relevant interconnection in the relevant direction, the MCP at the importing side of the interconnection is not higher than the MCP at the exporting side plus € 0,10.	*If the interconnection is being used efficiently, the TLC-calculated electricity exchanges will be such that either prices have converged (with a small tolerance to allow, inter alia, for rounding issues), or they have reached the physical ATC limit (in which case prices are likely to be different).*

Table 1- Market Coupling High Level Properties

3.3.1.2 Formulation

These constraints correspond to the following mathematical expressions, expressed with the correspondent notations and definitions:

	Mathematical formulation
HLP1	For each i and h, $P_{i,h} \geq 0$
HLP2	For each h, $\left\lvert \sum_{i} E_{i,h} \right\rvert \leq VT$
HLP3	For each $i \in$ {F, NL} and each h, $-ATC_{BE,i,h} \leq E_{i,h} \leq ATC_{i,BE,h}$
HLP4	For each $i \in$ {F, NL} and each h, $E_{i,h} > 0 \Rightarrow P_{BE,h} - P_{i,h} > -PT$ $E_{i,h} < 0 \Rightarrow P_{i,h} - P_{BE,h} > -PT$
HLP5	For each $i \in$ {F, NL} and each h, $(-ATC_{BE,i} < E_i < ATC_{i,BE})$ $\Rightarrow \lvert P_{BE,h} - P_{i,h} \rvert < PT$

Table 2- Mathematical formulation of Market Coupling High Level Properties

	Notations
i,j	Represents a Hub and ranges over {FR, BE, NL} FR: France, BE: Belgium, NL: the Netherlands
h	Represents a Settlement Period and ranges over {1, ..., 24}
$ATC_{i,j,h}$ (MW)	Represents the value of the ATC from i to j for Settlement Period h
$E_{i,h}$ (MW)	Represents the Net Position of TSO_i on power $exchange_i$ for Settlement Period h (positive if an export, negative if an import)
$P_{i,h}$ (€/MW)	Represents the Market Clearing Price of power $exchange_i$ for Settlement Period h
VT (MW)	Represents the volume tolerance level. This positive value is determined to allow rounding in the numerical computations of the Trilateral Market Coupling Algorithm. VT = 1MW
PT (€/MW)	Represents the price tolerance value. This positive value is determined to allow rounding in the numerical computations of the Trilateral Market Coupling Algorithm. PT = 0.1 €/MWh

Table 3- Notations for the mathematical formulation

3.3.2 Power exchanges High Level Properties

The following power exchanges High Level Properties are constraints that the Market Results must fulfil for each Settlement Period. They reflect the requirements of individual participants trading on the power exchanges.

	Description	Relevance
HLP6	A Divisible Hourly Offer is not accepted when the MCP is lower than the offer Price Limit;	*Divisible Hourly Offers are only contracted at prices greater than or equal to the offered price;*
HLP7	A Divisible Hourly Bid is not accepted when the MCP is higher than the bid Price Limit;	*Divisible Hourly Bids are only contracted at prices less than or equal to the bid price;*
HLP8	A Divisible Hourly Offer is not rejected when the MCP is higher than the offer Price Limit;	*All Divisible Hourly Offers with Price Limit smaller than the MCP are contracted;*
HLP9	A Divisible Hourly Bid is not rejected when the MCP is lower than the bid Price Limit;	*All Divisible Hourly Bids with Price Limit greater than the MCP are contracted;*
HLP10	A Divisible Hourly Order is not partially accepted unless the MCP is equal to the Price Limit of that Order;	*A Divisible Hourly Bid or Offer may be partially accepted, but only if the bid or offer Price Limit is equal to the MCP;*
HLP11	A Block Offer is not accepted when the average of MCPs over the relevant Settlement Periods is lower than the Price Limit of this Order;	*Block Offers may only be contracted if the average Market Clearing Price over the relevant Settlement Periods is greater than or equal to the offer Price Limit;*
HLP12	A Block Bid is not accepted when the average of MCPs over the relevant Settlement Periods is higher than the Price Limit of this Order;	*Block Bids may only be contracted if the average MCP over the relevant Settlement Periods is less than or equal to the bid Price Limit;*
HLP13	A Block Order is not partially accepted;	*A Block Bid or Offer should either be fully accepted or fully rejected;*
HLP14	An Order is not executed for a quantity in excess of the quantity specified in the Order.	*Volume order limits must be respected.*

Table 4- Power exchanges High Level Properties

4 Net Export Curves

It is important, before describing the algorithm, to introduce the concept of NEC. The NECX(*h*) of a market X is the Net Position QX(*h*) of this market as a function of the MCPX(*h*), i.e. the difference between total sales and total purchases at that price, provided that every Block Order is fixed to either a rejected or accepted state.

The NEC of each market for each Settlement Period of the following Day is determined by calculating the volume difference between Divisible Hourly Bids and Divisible Hourly Offers for each price level between the minimum and the maximum prices (extreme prices are harmonised between the power exchanges), after having considered accepted Block Orders as price-inelastic Divisible Hourly Orders on each Settlement Period they apply to. Depending on the market, Divisible Hourly Offers and Divisible Hourly Bids are defined in two different ways, either with points or with segments.

For a deeper understanding of the NEC concept, the construction of the two types of NECs is presented in the box below.

- If Divisible Hourly Bids and Offers are defined with price-quantity couples, the curve is obtained by joining the points to each other. Thus the NEC is (piecewise) linear, as shown in the picture below. This type of NEC is used by the French market Powernext.

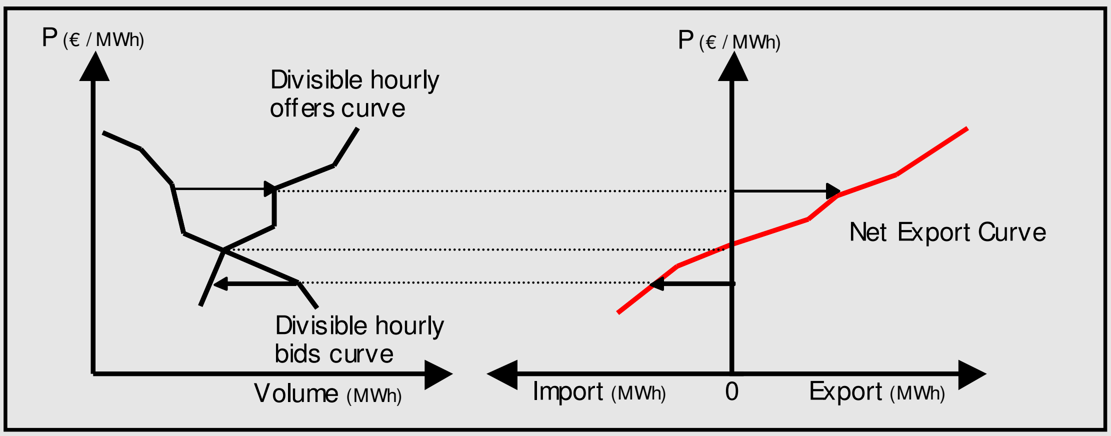


Figure 3- Linear NEC

- If Divisible Hourly Bids and Offers are defined with price-quantity range pairs —i.e. for each price a range of feasible quantities is defined—, the curve is obtained by joining the segments to each other. Thus the NEC is a stepwise curve, as shown in the figure below. This kind of NEC is used by the Belgian market Belpex and by the Dutch market APX.

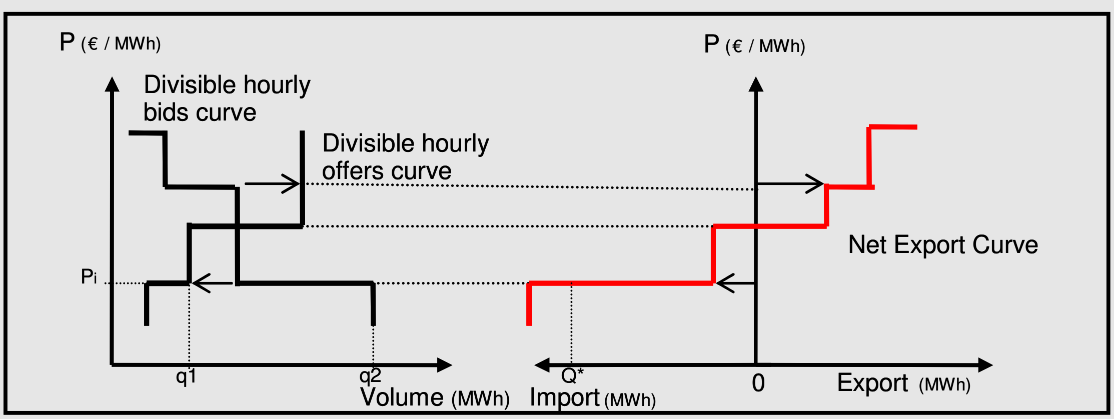


Figure 4- Stepwise NEC

On each horizontal segment of the NEC, a range of quantities is feasible for a given price. The executed volume (bids + offers) on the power exchange is maximised for one quantity of this range; this quantity is written Q*. The Q* quantity is not necessarily reached at the extremity of the horizontal segment, but can be reached on any point of the segment.

For example, at the price Pi, the NEC has a horizontal segment and the executed volume on the power exchange is maximised if the offered volume is q1 and the bid volume is q2. Hence Q* is equal to q1 minus q2; this quantity is indicated on the NEC. Note that the Q* volume is not at the extremity of the horizontal segment.

Box 1 Construction of NECs

A market may construct several NECs for every Settlement Period, considering every possible combination of accepted and rejected Block Orders. These combinations of accepted Block Orders are called “Winning Subsets”. A particular instance of the NEC is the block-free NEC, constructed strictly from Divisible Hourly Orders, thus excluding all Block Orders.

All other possible NECs of the same Settlement Period can be derived from the block-free NEC, as they only differ from each other by the Winning Subset. For the NEC construction, the Block Orders within the Winning Subsets are represented by price-inelastic Divisible Hourly Orders. As a result, the hourly demand and/or offer curves shift to the right. The difference between the shifts of the offer curve and the demand curve - the net volume resulting from the Winning Subset for a particular Settlement Period - is called the Net Block Volume (NBV). Thus each possible NEC for a particular Settlement Period is a horizontal translation of the block-free NEC by a NBV(*h,k*), as illustrated in Figure 5. The NBV can be either positive or negative. A Net Block Offer Volume is positive and causes the NEC to shift to the right while a Net Block Bid Volume is negative and causes the NEC to shift to the left.

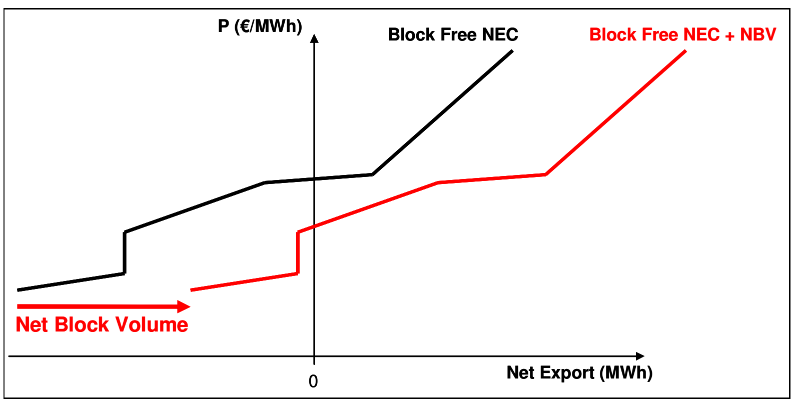


Figure 5- Shifted block-free NEC.

5 Overview of the Market Coupling process

Using the ATCs and NECs, the Trilateral Market Coupling Algorithm can determine for each Settlement Period the price and Net Position of each market (i.e. a point on the NEC). Now, as mentioned above, a NEC is built for a given set of accepted Block Orders (Winning Subset). When a set of NECs is used to determine the prices and the Net Positions of each market, the set of prices returned for each market may very well not be compatible with this assumed Winning Subset. The Winning Subset needs to be updated and the calculations run again with the derived new NEC. This procedure must be repeated until a stable solution is found.

As a consequence, the Trilateral Market Coupling Algorithm involves iterations between two modules:

- The coordination module which is in charge of the centralised computations (presented in detail in section 6);
- The block selector of each power exchange which performs the decentralised computations (presented in detail in section 7).

The iterative nature of the algorithm derives from the treatment of Block Orders, as explained above.

The data flows and calculations of the iterative algorithm are described in the rest of this section. Figure 6 gives a representation of the entire sequence of calculations required to perform Market Coupling. The dotted area defines the perimeter of the Trilateral Market Coupling Algorithm within that series of calculation.

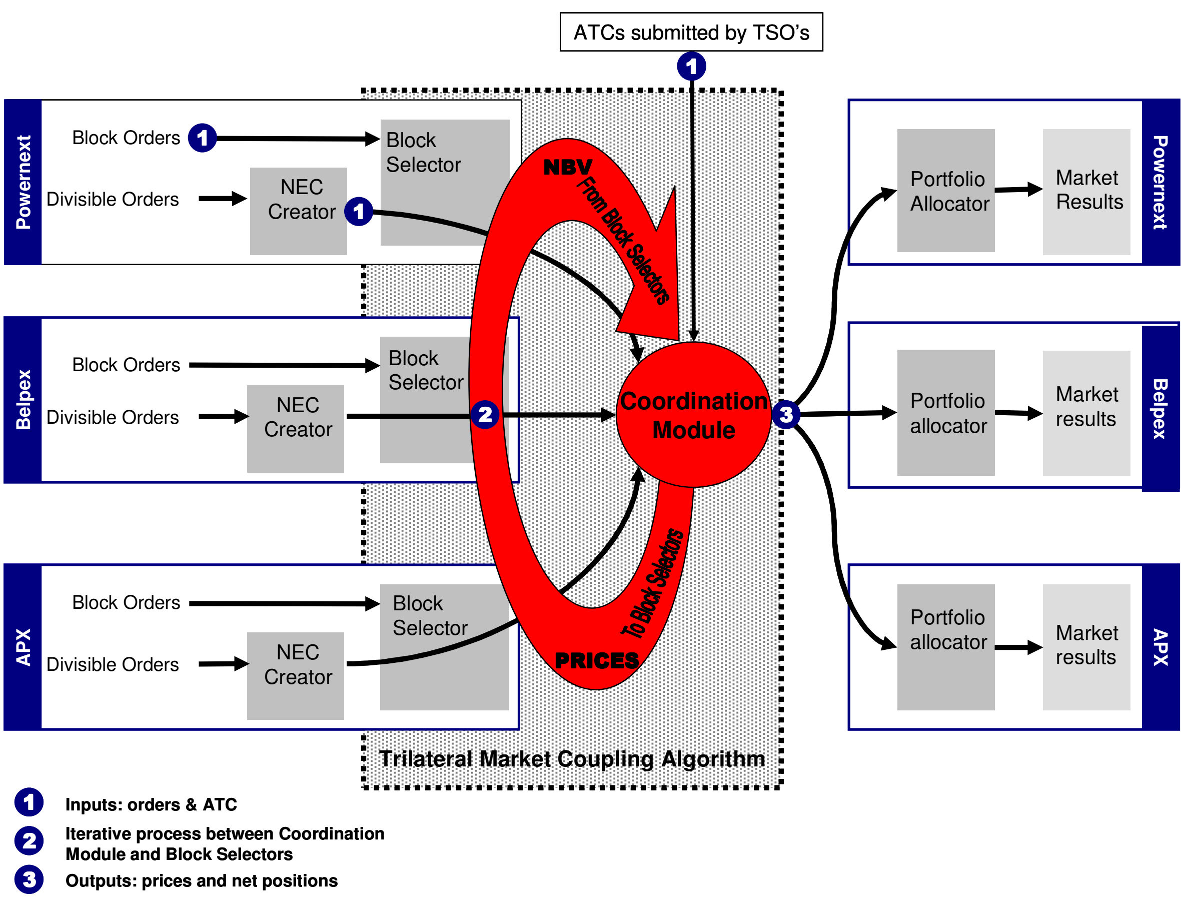


Figure 6 - Overview of the Market Coupling process

5.1 Initial calculations

Data collection

For each market and each Settlement Period of the following Day, the Divisible Hourly Orders are aggregated into a block-free NEC (see section 4) and the coordination module collects these block-free NECs.

For each market the Block Orders are collected by the local block selector.

The coordination module collects the ATCs, defined between each area, in each flow direction and for each Settlement Period.

Initialisation

The algorithm is initialised with a first Winning Subset including all Block Orders. The block selector of each market computes the initial NBV for each Settlement Period by selecting all the Block Orders. The initial NBVs are collected by the coordination module.

5.2 Iterative calculations

Coordination module (detailed in section 6)

At each iteration, the coordination module, for each Settlement Period:

- Takes as an input
  - For each market, the NEC obtained by translating the block-free NEC by the NBV received from the block selector;
  - For each border and direction, an ATC;
- Returns for each market a point of the NEC, i.e.
  - a price;
  - a Net Position;

such that the set of prices and Net Positions complies with the list of Market Coupling “pure” (i.e. with no tolerance levels) High Level Properties described in section 3.3.1. When the set of “pure” HLPs is not sufficient to determine a unique set of results, the coordination module applies additional price and quantity determination rules described later in sections 6.3.1 and 6.3.2. Details of the computations performed by the coordination modules are presented in section 6.2.

Block selector (detailed in section 7)

At each iteration, the block selector of each market:

- Receives as an input
  - A price for each Settlement Period, as determined by the coordination module;
- Returns as an output
  - A NBV for each Settlement Period.

For that purpose, the Block Selector proceeds in two steps: first, a “pure” Winning Subset is determined, where each Block Order is either selected or rejected on the basis of the set of prices received from the coordination module; second, the block selection is refined in order to avoid large oscillations or cycling behaviour. Details of the computations performed by the coordination modules are presented in section 7.

5.3 Final calculations

<u>Convergence</u>

The iterative process stops when a stable solution has been found, meaning that prices found for each market and for each Settlement Period are equal to those of the previous iteration.

At convergence, the coordination module returns to each power exchange a price and a Net Position for each Settlement Period. Each power exchange uses this data to determine the individual schedules of its participants/ portfolios (portfolio allocation phase) according to its own rules.

6 Functioning of the coordination module

This section describes the computations performed by the coordination module to produce results compliant with the High Level Properties (sections 6.1 and 6.2). It also describes the price and quantity determination rules which are applied when the HLPs are not sufficient to determine a unique solution (section 6.3).

6.1 Solving two-Market Coupling

In the case of two markets, the prices and the amount of electricity exchanged between the markets can easily be determined with NECs. The price read on the NEC for a zero import quantity is the isolated MCP of the market - i.e. before electricity is exchanged between the areas. The market with the highest isolated MCP will import electricity from the market that has the lowest isolated MCP. The importing market has its NEC inverted as shown in the figure below, since for a two-market case, imports on one side are exports on the other. Hence the equilibrium price and quantity for the two markets is reached at the intersection point of the two curves. Indeed, at this point the prices of each market are equal and the readiness of Market 1 to export electricity is equal to the readiness of Market 2 to import electricity.

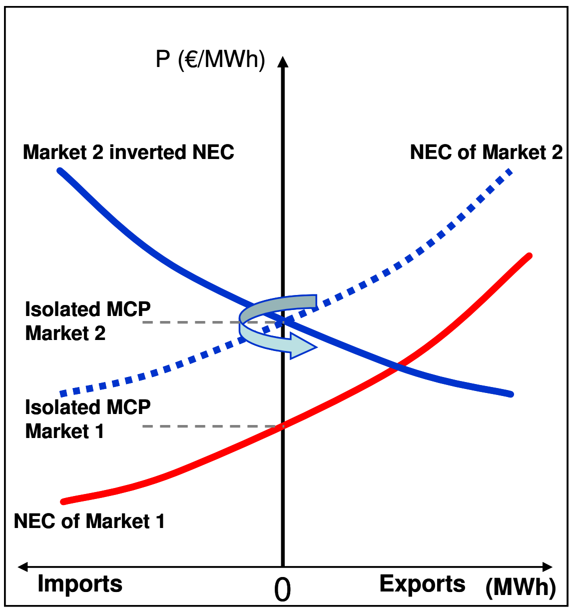


Figure 7- NEC of importing market (Market 2) is inverted

The prices between the two markets are equal if sufficient ATC is available between the two markets —i.e. non-congested situation. Otherwise, the two NECs cannot intersect and the amount of electricity exchanged between the two markets is equal to the ATC value. As a result, Market 1 and Market 2 have different prices — i.e. congested situation. These two cases are illustrated in the figure below, where the NEC of Market 2 has been inverted.

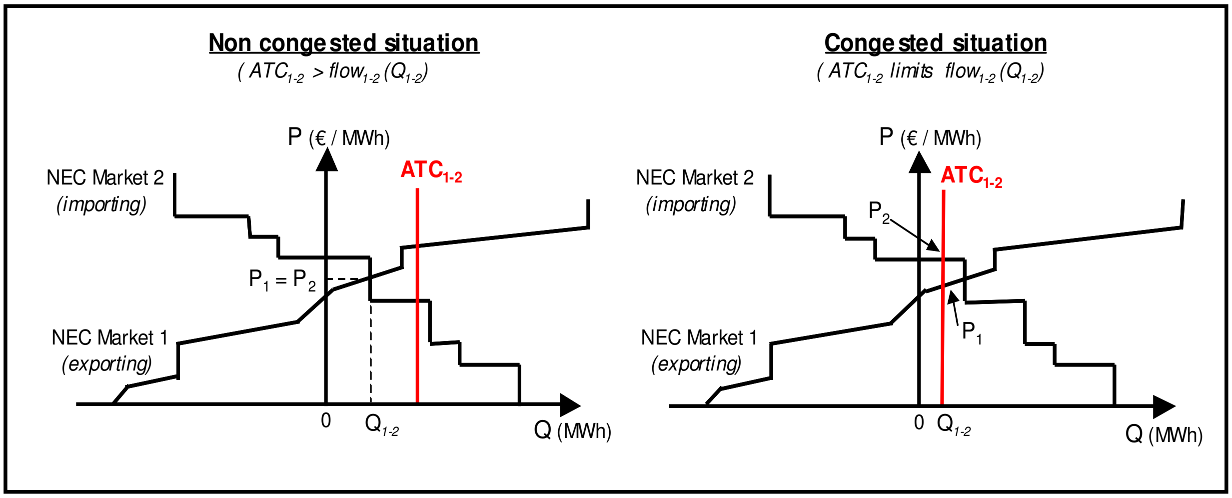


Figure 8- Computation of MCP and MCV using NECs

6.2 Solving three-Market Coupling

<u>Principle of the calculations</u>

For three markets, the prices and the amount of electricity exchanged between the markets cannot be determined as easily as for the two markets case since the export of one market is not necessarily imported by the other (unique) one; several steps in the computations are needed. First the three markets are ordered regarding their isolated MCP: M1 is the market with the lowest isolated MCP and M3 is the market with the highest isolated MCP ($P_0 1 < P_0 2 < P_0 3$). Then two 2-Market-Coupling steps are performed:

- Step 1: the lowest isolated MCP market (M1) exports to the highest isolated MCP market (M3) (potentially via M2 if M2 is Belgium), which causes P1 to increase and P3 to decrease; this continues until either one of those markets
  - a) gets isolated; this is the case when one market has used its entire ATC and cannot export or import anymore, or
  - b) "merges" with the market M2 with (middle isolated MCP): this is the case when P1 or P3 equals to P2.
- Step 2:
  - In case a), the isolated market remains isolated and a two-Market Coupling takes place between the two other markets;
  - In case b), the two "merged" markets jointly export to or import from the third market. This amounts to a two-Market Coupling between a combined market on the one side and the third market on the other side. Figure 9 illustrates the case where Market 1 and Market 2 export jointly to Market 3.

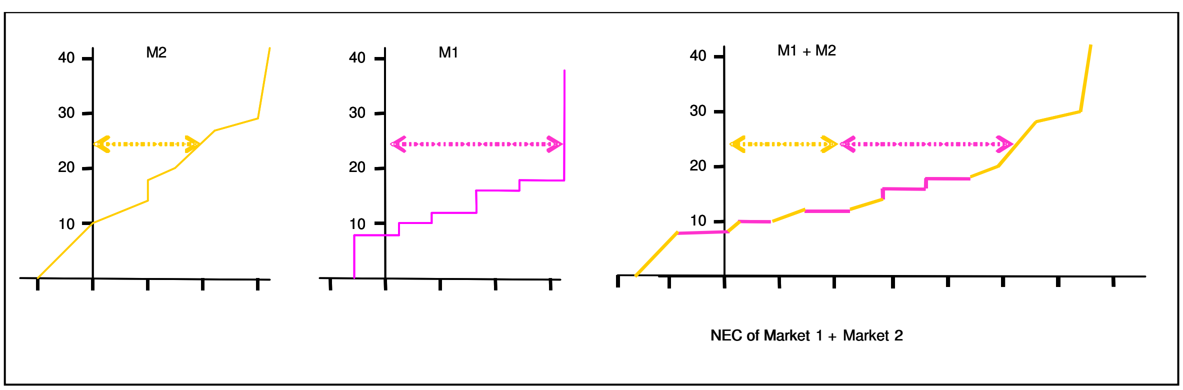


Figure 9 – Aggregation of two NECs

The section below illustrates the several possible cases for step 2 through an example.

The NECs of the three markets are represented in figure 6. The isolated prices of the three markets are ordered as follows: $P_0BE < P_0FR < P_0NL$, it means M1 is Belgium, M2 is France and M3 are the Netherlands.

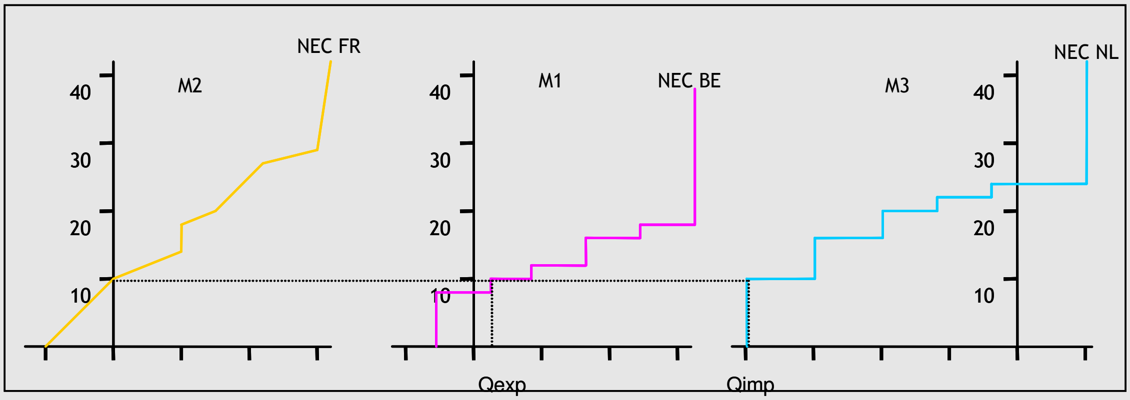


Figure 10- Individual NECs of the three markets, ATCs are very large.

Step 1

Market M1 exports electricity to market M3.

The amount of electricity exchanged between market M1 and market M3 depends on the values taken by the Q_{exp} and Q_{imp} quantities that are represented on figure 10. The Q_{exp} quantity represents the volume that – were there no transmission constraints - market M1 would be willing to export at market M2's isolated MCP. The Q_{imp} quantity represents the volume that –were there no transmission constraints - market M3 would be willing to export at the isolated MCP of market M2. If the Q_{exp} (respectively Q_{imp}) quantity is greater than the ATC for exporting (respectively importing) electricity, then Q_{exp} (respectively Q_{imp}) is limited to the ATC value. During step 1, the amount of electricity exported from market M1 to market M3 is equal to the minimum value between Q_{exp} and Q_{imp}.

Step 2

The computations performed in step 2 are subject to the values taken by Q_{exp} and Q_{imp}:

- In case the smaller of Q_{exp} and Q_{imp} is limited by the transfer capacity, a market (either M1 or M3) is "isolated"; it means no transfer capacity is available for additional exchanges between this market and the two other ones. A 2-Market Coupling computation is performed between the two remaining markets.
- In case the smaller of Q_{exp} and Q_{imp} is not limited by the transmission constraint, the NEC of market M2 is combined with market M1 if Q_{exp} is smaller than Q_{imp} and with market M3 if Q_{imp} is smaller than Q_{exp}. It is presented below how the NECs of two markets are combined and how the 2-Market Coupling computation is performed between the combined NEC and the remaining market.

NEC combination

We consider that Q_{exp} and Q_{imp} are not constrained by transmission constraints and Q_{exp} is smaller than Q_{imp}. Hence the NECs of market M1 and market M2 are combined, as presented in figure 11. Since M3 is the importing market, its NEC is flipped horizontally, see figure 12.

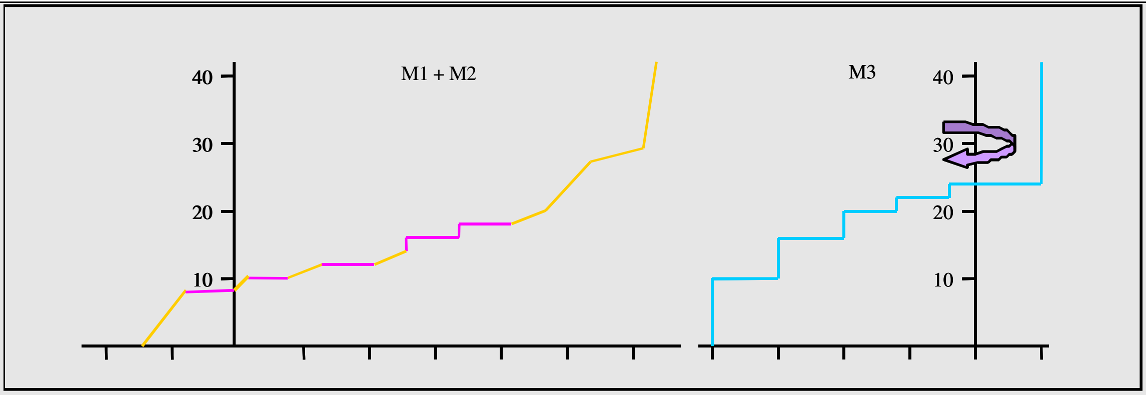


Figure 11- Combined export curves M1+M2 and individual curve M3 (to be flipped)

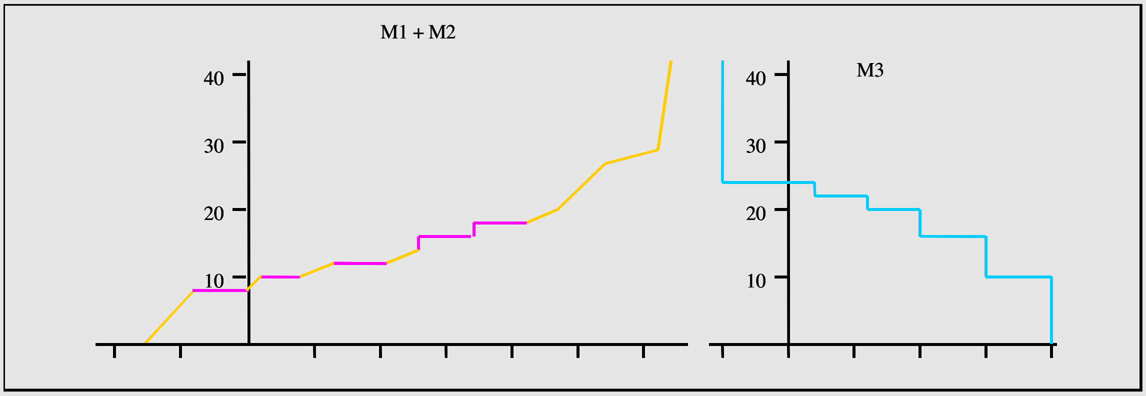


Figure 12- Combined export curves M1+M2 and individual import curve M3

Based on the congestion patterns, there are now four possible scenarios:

Scenario 1- No congestion limitations, full price convergence.

Figure 13 shows the combination of the NECs in case there is no limitation by ATCs and the prices of the three markets converge to 16. The figure shows also that both market M1 and market M2 have contributed to the import volume of market M3 (see the yellow and purple line pieces). The individual market volumes of markets M1 and M2 are found by projecting the equilibrium price 16 on the individual market M1 and market M2 NECs.

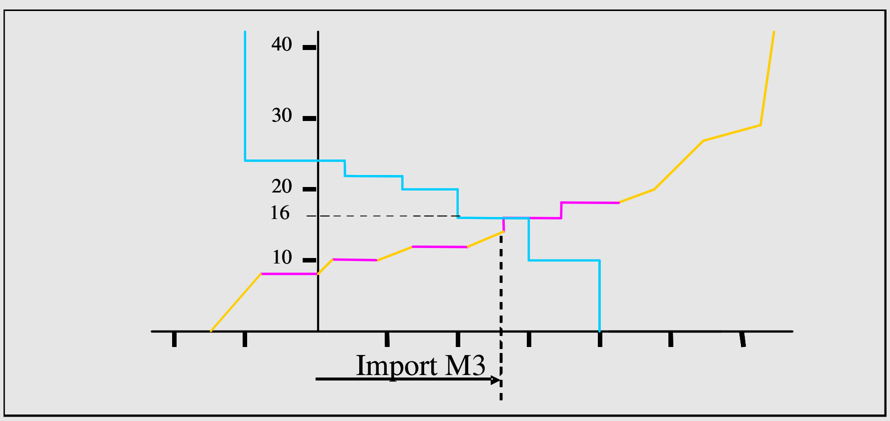


Figure 13- No congestion limitations, full price convergence

Scenario 2- ATC limitation for market 3 (market 3 is isolated), markets 1 and 2 still have full price convergence.

Figure 14 shows the situation where ATC23 limits the imports to market M3. Because the markets M1 and M2 are merged their prices are equal to P1 = P2 = 12. Since market M3 became isolated its price is higher and equals P3 = 20. The individual market volumes of markets 1 and 2 are found by projecting the equilibrium price for these markets (12) on the individual market M1 and market M2 NECs.

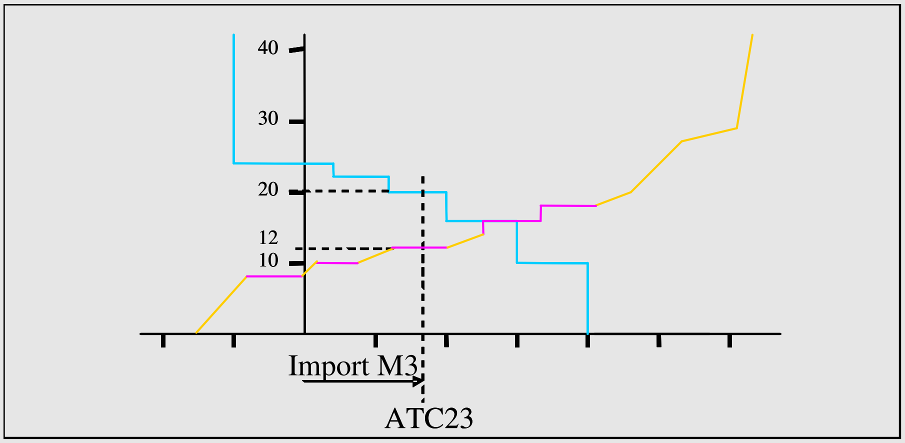


Figure 14- ATC limitation between markets 2 and 3, markets 1 and 2 still have full price convergence

Scenario 3- ATC limitation for market 1 (market 1 is isolated), markets 2 and 3 still have full price convergence.

In figure 15 the ATC12 limits the exports from M1 which causes its price to stick at P1=10. Between M2 and M3 there is no restriction so the prices merge to P2 = P3 = 16. The individual market volumes of markets 1 and 2 are found by projecting the equilibrium price for these markets (respectively 10 and 16) on the individual market M1 and market M2 NECs.

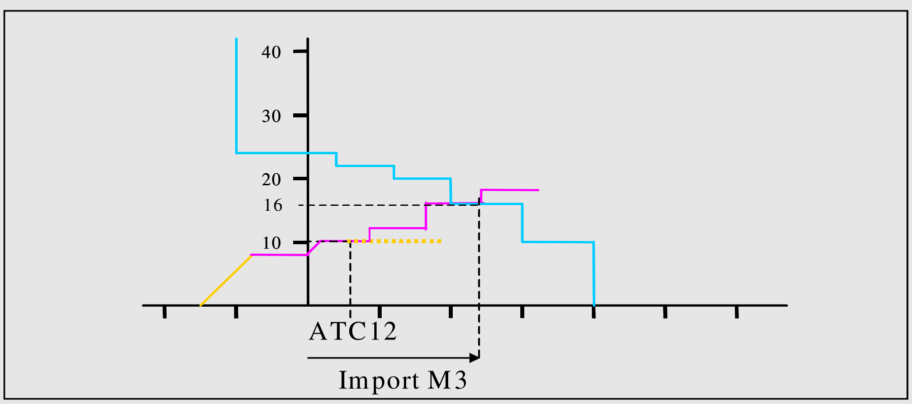


Figure 15- ATC limitation between markets 1 and 2, markets 2 and 3 still have full price convergence

Scenario 4- ATC limitation between markets 1, 2 and 3, three different prices.

Figure 16 presents the situation where both ATCs are restrictive. As a consequence all prices are different. The individual market volumes of markets 1 and 2 are found by projecting the equilibrium price for these markets (respectively 10 and 16) on the individual market M1 and market M2 NECs.

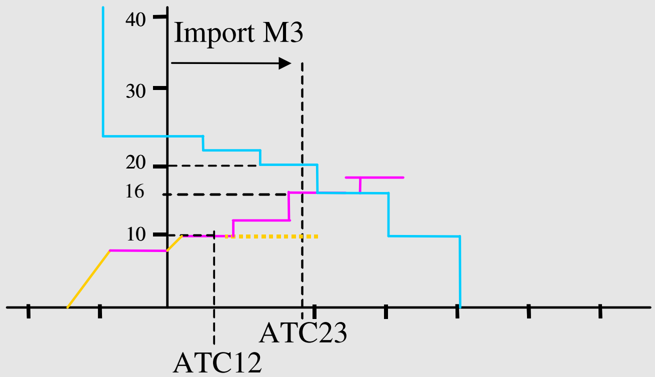


Figure 16- ATC limitation between markets 1 and 2 and between markets 2 and 3, three different prices

In a similar way, if Q_{imp} were lower than Q_{exp}, we would also have a combined NEC (between market M2 and market M3) and four scenarios as described before.

Box 2 Detailed coordination module computations for three markets

6.3 Price and quantity determination rules

In some cases the calculations above produce outcomes where a range of prices or a range of quantities are possible, while one single combination of price and quantity is required as outcome for each individual period. In this case, choices, which comply with the High Level Properties, are necessary to come to establishment of hourly prices and quantities. Price and quantity determination rules are used for this purpose.

6.3.1 Quantity determination rules

For a given price, a range of volumes may be possible for stepwise NECs. At maximum and minimum prices, several volumes may also be possible for linear NECs; they correspond to price-inelastic Bids and Offers. In that case, a horizontal segment is graphically visible on the NEC. Hence the NEC calculations may lead to one, two or three quantity indeterminations.

For a deeper understanding of the algorithm, the rules applied in case of one, two or three quantity indeterminations are presented in the next box. The general rationale behind the rules is that when several sets of Net Positions are possible for the same equilibrium prices:

- The set of Net Positions should be chosen so as to maximise total executed volume;
- In case several volume-maximising sets of Net Positions are possible, the volume should be spread evenly between the markets.

1. One quantity indetermination

The total net export quantity of the three markets has to be null (see HLP2). Therefore if there is quantity indetermination for one market only, its quantity is easily determined according to the quantities of the two other markets.

2. Two quantity indeterminations

For a given price, different volumes are possible for two markets. In that case, the volumes are defined so as to maximise the total executed volume; using the Q* volumes (black dots in the figure below). However, if we apply such volumes, the flow may be inconsistent and the total net export of the three markets may be different from zero. This volume is called imbalance in the figure below and is shared between the two markets as equally as possible.

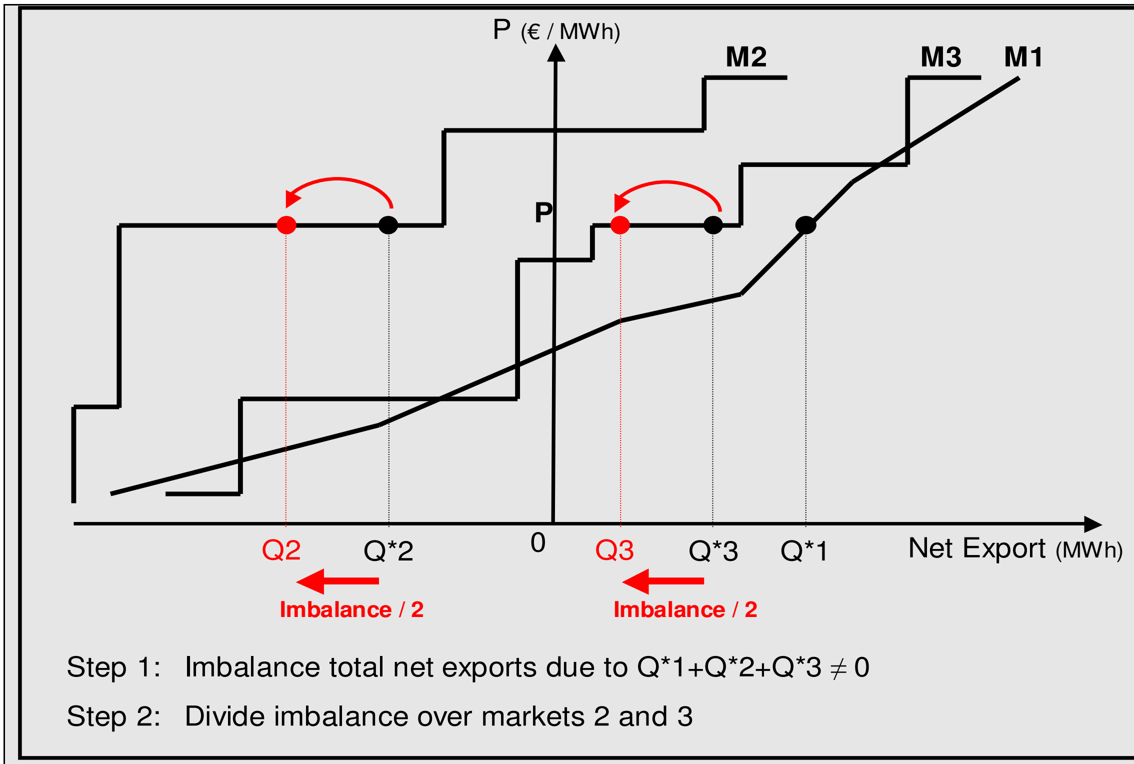


Figure 17- Two quantity indeterminations; equilibrium price is P. Imbalance volume is equally shared between M2 and M3.

3. Three quantity indeterminations

At extreme prices, linear NECs as well as stepwise NECs may have a horizontal segment. Therefore if the three markets are at an extreme price, specific rules have to be applied to determine the Net Positions of the three markets. The rules are applied depending on the number of markets which were initially —i.e. for a null net export— at an extreme price.

If one market was initially at an extreme price, the Q* rule is applied to the two other markets; and since the sum of the Net Positions has to be null, the Net Position of the third market is easily determined. However the Net Position calculated for the third market might not be reachable. In this case the maximum possible quantity is taken for this market. Net Positions for the two other markets are determined regarding the rules defined for two quantity indeterminations (Q* rule).

If two markets are initially at maximum price or if two markets are initially at minimum price, the Q* rule is applied to the third market. Net Positions for the two other markets are determined according to the rules defined for two quantity indeterminations.

If all the three markets are initially at the maximum price or all the three markets are initially at the minimum price, the quantities exchanged between the markets are null.

Box 3 Quantity determination rules

6.3.2 Price determination rules

Once the Net Positions are calculated for each market, a range of feasible prices may be possible for linear NECs as well as for stepwise NECs. Graphically, it means that equilibrium is found on vertical segments of the NECs. When such indeterminacy arises, the middle of the feasible range is chosen.

If several vertical segments have common prices, the middle of the common range is chosen. In the following picture, the price applied to the three markets is P, which is the middle of the common range on the three NECs.

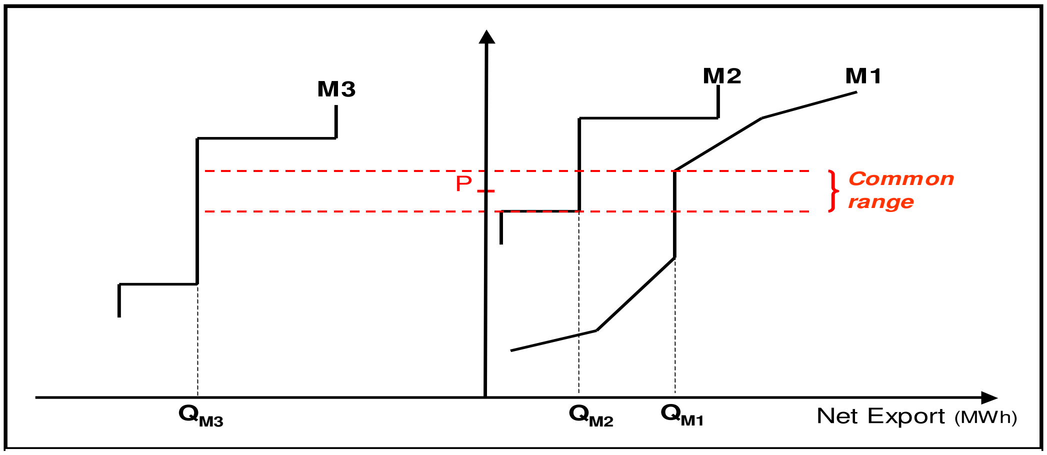


Figure 18- Three price indeterminations; equilibrium price is the middle of common range.

Other cases are described in the box below. They all follow the same philosophy.

A vertical segment may also overlap independently with the two other ones. Such a situation happens when the market overlaps exactly at the ATC value of one or both borders. Prices are then set taking into account the geographical configuration of the Region, in order to respect the High Level Properties.

If Powernext's price can be equalised with either the price of Belpex or the price of APX, it is equalised with the Belpex price at the middle of the common range. If APX's price can be equalised with either the price of Belpex or the price of Powernext, it is equalised with the Belpex price at the middle of the common range (see Figure 19). These rules are applied if the market overlaps exactly at the ATC value of one or both borders.

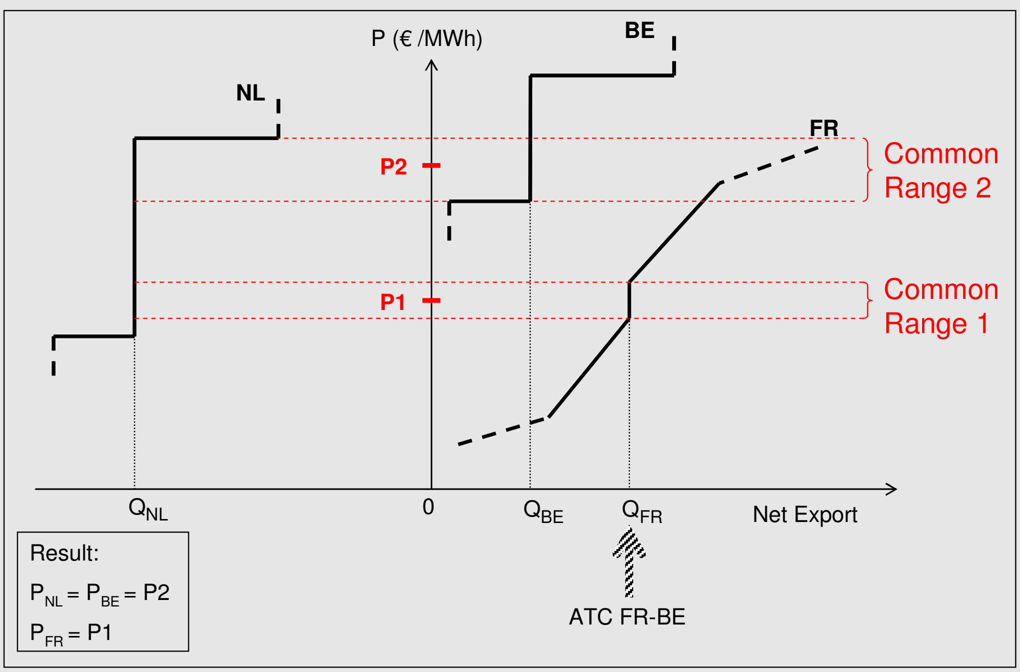


Figure 19- APX's NEC independently overlaps Powernext's and Belpex's NECs.

If Belpex's price can be equalised with either that of APX or that of Powernext, and if only one border is congested, then Belpex's price is set in the middle of the common range with the non-isolated market price (e.g. APX in the figure below).

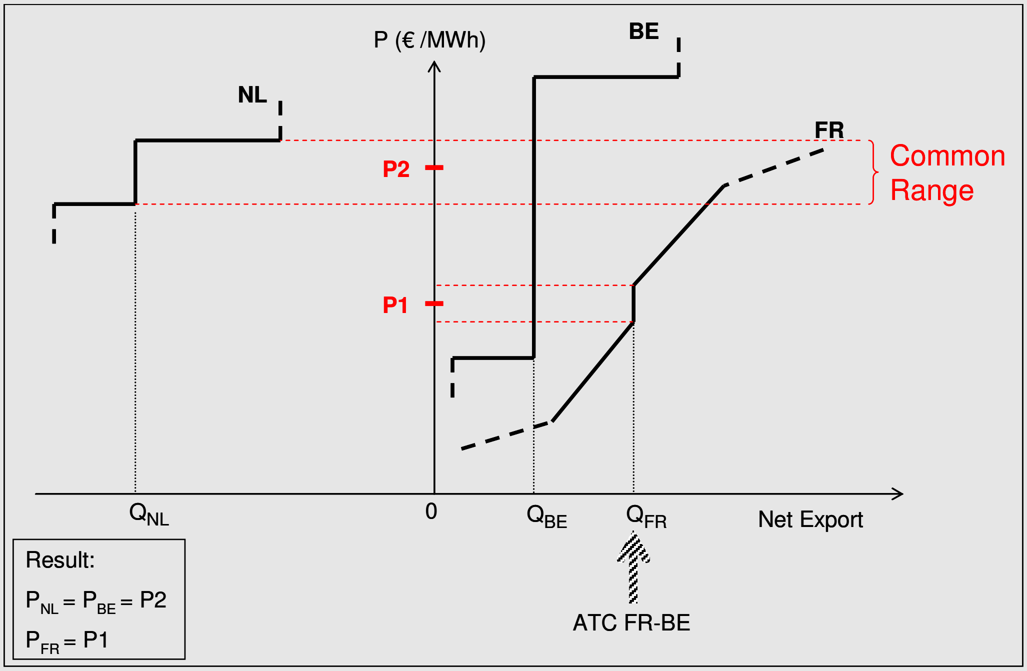


Figure 20- Belpex's NEC independently overlaps APX's and Powernext's NECs. ATC FR-BE is fully utilised.

In the case where both borders are congested and Belpex's NEC overlaps independently with the two other NECs, then the prices of APX and Powernext are determined in the middle at their own possible range. Then the Belpex prices determined regarding the flow configuration on the borders. If Belpex is exporting to APX and Powernext, Belpex's price is the minimum between Powernext's and APX's prices; on the contrary if Belpex is importing from APX and Powernext, Belpex's price is the maximum between Powernext's and APX's prices. If Powernext exports to Belpex, which exports to APX, or if APX exports to Belpex which exports to Powernext, then Belpex's price is the average between the two other power exchange prices (see Figure 21).

If the ATC is null between two regions, the rules are slightly different: Belpex's price is equal to the non-isolated market price. Whenever this price cannot be reached, Belpex closest possible price is taken. If both ATCs are null, price on Belpex is the middle of its own price range.

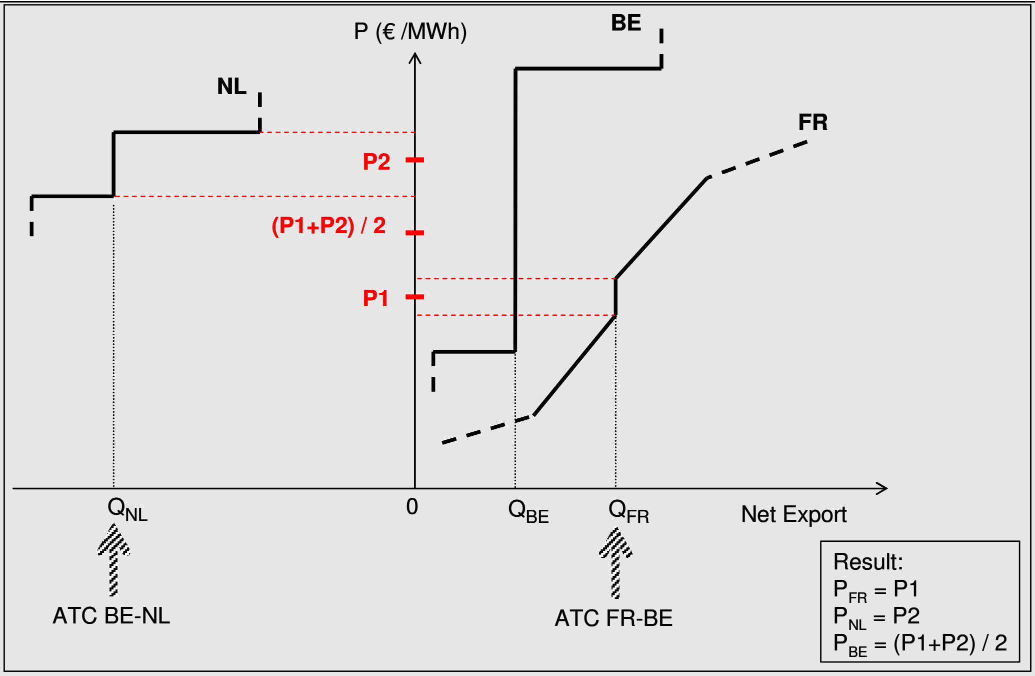


Figure 21- Belpex's NEC independently overlaps APX's and Powernext's NECS. Both borders are congested.

Box 4 Price determination rules

7 Functioning of the block selector

This section describes the computations performed by the block selectors to determine the set of accepted Block Orders at each iteration.

7.1 Definition of the Winning Subset

The Winning Subset is the set of accepted Block Orders at each iteration. The Net Block Volumes (NBVs) for each Settlement Period will be computed taking into account the Block Orders enclosed in the Winning Subset. At the first iteration, all Block Orders are accepted: the Winning Subset is made of all Block Orders. For the next iterations, the Winning Subset comprises the Block Orders accepted reflecting the prices returned by the coordination module:

- If the average market price is higher than — or equal to — a Block Offer's Price Limit, then the block is accepted;
- If the average market price is lower than — or equal to — a Block Bid's Price Limit, then the block is accepted;
- all other blocks are rejected.

7.2 Adjustment of the Winning Subset

In a second step, the Winning Subset needs to be adjusted. Indeed, it may be impossible to find a solution without rejecting "paradoxically" some Block Orders. A Paradoxically Rejected Block Order (PRB) is a Block Order that is rejected in the market results although it appears that it should have been accepted considering the MCPs. However, if these Block Orders were accepted, the equilibrium would have been adapted in such a way the Block Order would no longer be compatible with these new MCPs. Typically the algorithm would cycle in these cases as follows: a certain Block Order is accepted at iteration k, the coordination module computes new MCPs at iteration k+1, the Block Order is rejected at iteration k+1, the coordination module computes new MCPs at iteration k+2, the Block Order is accepted again at iteration k+2 … in such case it is likely that without rejecting such Block Order no solution can be found.

In order to prevent the algorithm from cycling and to ensure convergence in a reasonable time, a number of rules are implemented to allow paradoxical rejection of some Block Orders. The main assumption of such rules is that Block Orders rejected at the previous iteration and accepted at the current one are considered as potential PRBs. At each iteration, it is made increasingly difficult for such blocks to re-enter the Winning Subset so that cycles are less likely to occur as the number of iterations increases. Eventually, in order to force convergence, if the algorithm has not stabilised by a predefined number of iterations, Block Orders cannot re-enter anymore the Winning Subset; the algorithm converges a few iterations later.

The potential PRBs are ordered by the increasing difference between the Price Limit of the Block Order and the average MCPs of the relevant Settlement Periods (this difference being called ∆P). Then, the *n* first Block Orders for which the sum of these ∆Ps is smaller than a defined parameter ∆P are paradoxically rejected. The block selector thus rejects firstly potential PRBs which price is the closest to the MCPs. Indeed, it is less acceptable to reject paradoxically a Block Order which Price Limit is far from the MCPs than a Block Order which Price Limit is close to the MCPs.

The greater the ∆P value, the fewer the potential PRBs accepted. The value of the ∆P parameter is adapted at each iteration so as to gradually further restrict the re-insertion of Block Orders in the Winning Subset, but also so as to avoid large oscillations of the algorithm from one iteration to the next that could result in PRBs with a Price Limit far from the MCPs.

Complementary stabilisation and reintegration rules are implemented by the block selector, with the same view of avoiding large oscillations from one iteration to the next.

8 HLPs in case of decoupling

Table 5 lists the High Level Properties applicable in case of decoupling of one coupled power exchange, to the two power exchanges that remain coupled.

Note that if the Belgium market decouples, Powernext and APX can still be coupled. ATCs between France and the Netherlands are in this case the minimum of the ATCs in each direction:

- $ATC_{FR,NL,h} = \min (ATC_{FR,BE,h}\ ,\ ATC_{BE,NL,h})$ for all h
- $ATC_{NL,FR,H} = \min (ATC_{BE,FR,h}\ ,\ ATC_{NL,BE,h})$ for all h

	3-market case	FR is decoupled	BE is decoupled	NL is decoupled
HLP1	$P_{FR,h} \geq 0$ $P_{BE,h} \geq 0$ $P_{NL,h} \geq 0$	$P_{BE,h} \geq 0$ $P_{NL,h} \geq 0$	$P_{FR,h} \geq 0$ $P_{NL,h} \geq 0$	$P_{FR,h} \geq 0$ $P_{BE,h} \geq 0$
HLP2	$\lvert E_{FR,h} + E_{BE,h} + E_{NL,h} \rvert \leq VT$	$\lvert E_{BE,h} + E_{NL,h} \rvert \leq VT$	$\lvert E_{FR,h} + E_{NL,h} \rvert \leq VT$	$\lvert E_{FR,h} + E_{BE,h} \rvert \leq VT$
HLP3	$- ATC_{BE,FR,h} \leq E_{FR,h} \leq ATC_{FR,BE,h}$ $- ATC_{BE,NL,h} \leq E_{NL,h} \leq ATC_{NL,BE,h}$	$- ATC_{BE,NL,h} \leq E_{NL,h} \leq ATC_{NL,BE,h}$	$- ATC_{BE,FR,h} \leq E_{FR,h} \leq ATC_{FR,BE,h}$ $- ATC_{BE,NL,h} \leq E_{NL,h} \leq ATC_{NL,BE,h}$	$- ATC_{BE,FR,h} \leq E_{FR,h} \leq ATC_{FR,BE,h}$
HLP4	$E_{FR,h} > 0 \Rightarrow P_{BE,h} - P_{FR,h} > -PT$ $E_{FR,h} < 0 \Rightarrow P_{FR,h} - P_{BE,h} > -PT$ $E_{NL,h} > 0 \Rightarrow P_{BE,h} - P_{NL,h} > -PT$ $E_{NL,h} < 0 \Rightarrow P_{NL,h} - P_{BE,h} > -PT$	$E_{NL,h} > 0 \Rightarrow P_{BE,h} - P_{NL,h} > -PT$ $E_{NL,h} < 0 \Rightarrow P_{NL,h} - P_{BE,h} > -PT$	$E_{FR,h} > 0 \Rightarrow P_{NL,h} - P_{FR,h} > -PT$ $E_{FR,h} < 0 \Rightarrow P_{FR,h} - P_{NL,h} > -PT$ $E_{NL,h} > 0 \Rightarrow P_{FR,h} - P_{NL,h} > -PT$ $E_{NL,h} < 0 \Rightarrow P_{NL,h} - P_{FR,h} > -PT$	$E_{FR,h} > 0 \Rightarrow P_{BE,h} - P_{FR,h} > -PT$ $E_{FR,h} < 0 \Rightarrow P_{FR,h} - P_{BE,h} > -PT$
HLP5	$(-ATC_{BE,NL} < E_{NL} < ATC_{NL,BE})$ $\Rightarrow \lvert P_{BE,h} - P_{NL,h} \rvert < PT$ $(-ATC_{BE,FR} < E_{FR} < ATC_{FR,BE})$ $\Rightarrow \lvert P_{BE,h} - P_{FR,h} \rvert < PT$	$(-ATC_{BE,NL} < E_{NL} < ATC_{NL,BE})$ $\Rightarrow \lvert P_{BE,h} - P_{NL,h} \rvert < PT$	$(-ATC_{BE,FR} < E_{FR} < ATC_{FR,BE})$ and $(-ATC_{BE,NL} < E_{NL} < ATC_{NL,BE})$ $\Rightarrow \lvert P_{NL,h} - P_{FR,h} \rvert < PT$	$(-ATC_{BE,FR} < E_{FR} < ATC_{FR,BE})$ $\Rightarrow \lvert P_{BE,h} - P_{FR,h} \rvert < PT$

Table 5- Market Coupling High Level Properties in case of decoupling