Auction-Based Market Coupling – Integrating the Exchange and Bilateral Markets

ANDRAŽ ŠAVLI, BORUT RAJER, TOMAŽ LAJOVIC
Borzen, Power Market Operator
Dunajska 128a, 1000 Ljubljana
SLOVENIA
http://www.borzen.si

Abstract: - The European Union has adopted implicit methods of capacity allocation, and especially market coupling, as the preferred means for congestion management in the view of Internal Electricity Market consolidation. This will greatly influence the future development of the South-Eastern European electricity market trough the ECSEE Treaty. In this paper, a case-study of market coupling on a coordinated grid model (PTDF&BC) delivering maximized social welfare is presented with a newly developed method which implicitly matches bids and offers for energy and at the same time allocates cross-border capacities to the energy from the power exchange and to the energy from bilateral contracts. The method utilizes price-difference bids to serve the OTC market, thus fully integrating all major market situations present today. The case-study investigates the price formation process in 4 similar cases of different complexity: (1) single product energy markets with no network limitations among them, (2) single product energy markets with transfer limitations, (3) single product energy markets including price-difference bid with transfer limitations and (4) multiple product energy markets with transfer limitations.

Key-Words: - Congestion Management, Coordinated Grid Model, Electricity Market, Implicit Auctions, Market Coupling, Price-difference Bids

1 Introduction

Recently Market Coupling has been, as a method of implicit capacity allocation, recognized as the most effective system that could lead to the final consolidation of the EU Internal Electricity Market. Based on the EuroPEX's Decentralised Market Coupling initiative [1] and the subsequent joint work of EuroPEX and ETSO resulting in their Flow-based Market Coupling proposal [2], the European Commission has included these principles into the Congestion Management Guidelines that form part of the EU Regulation 1228/2003 on conditions for access to the network for cross-border exchanges in electricity [3]. As a part of the *acquis communautaire* these Guidelines will apply to the countries signatories of the ECSEE Treaty as well once it is fully in force.

Borzen has approached the challenges of market coupling mechanisms following the abovementioned principles together with KORONA Power Engineering and developed a market coupling algorithm using mixed-linear programming solving methods. A dedicated simulation software program running on the Windows platform has been used to provide for the case-study presented in this paper.

2 Auction Based Market Coupling

As a base for the mechanism development, a decentralized market coupling method was used. The method, introduced by EuroPEX and further developed jointly with ETSO, is believed to deliver an efficient outcome while taking into account loop flows, bilateral contracts, block bids, and counter-flows in a very flexible way and would be easy to develop progressively over time. The method makes all cross-border capacity available at the day-ahead/within-day stage. This enables the optimization of physical network usage, while forward price risk can be managed through financial contracts.

This mechanism was brought to the level so:

- it can consider any network topology, as long as the PTDF matrix is given,
- it can apply the PTDF matrix to determine the impact of transaction scheduling on interconnections loading,
- it enables trading with different electrical energy products,
- it enables cross-product matching, and
- it enables price-difference (bilateral) bids.

A new solution of the method presented in this paper with a new objective function in the optimization procedure gives an answer to maximization of social welfare of market coupling. **Price-difference bids** (e.g. bids to execute a bilateral cross-border contract) are handled via the power exchanges, thus enabling implicit matching of bids and offers for energy while at the same time allocating cross-border capacities to the energy from power exchanges or bilateral contracts. The bilateral contract is scheduled and the cross-border capacity is allocated to the bilateral contract whenever its bid price is higher than the price difference between the markets. This also includes negative bids for counter-flows, where the applicants are paid the price difference between markets, as the flow is in the opposite direction of congestion.

To determine the impact of cross-border energy exchanges on the loading of interconnections, the algorithm uses a coordinated model of the grid in terms of power transfer distribution factors and bottleneck capacities (PTDF&BC) matrix instead of a set of bilaterally agreed Net Transfer Capacity values (NTC). The algorithm is therefore in line with the latest guidelines in this field. When congestion occurs, the system automatically creates different price zones. The most exact determination of loading would be accomplished by a load flow calculation, but this would reflect in longer calculation times, especially when multiple calculation is required. The load flow equations were therefore simplified which lead to the formulation of PTDFs.

As common for every power exchange, the first step of the procedure is the construction of aggregate curves and bid-matching. In this part of the calculation, aggregate demand and supply curves are used to form the so-called net-export curves. They represent the input data for the mechanisms optimization program and determine the market electricity price depending on export or import electricity volume. When there is no export or import, the area price is the isolated market clearing price (please refer to [4] for details about PTDFs, and net-export curves).

3 Social Welfare

The maximization of social welfare, with consideration of price-difference (bilateral) bids, was selected as the objective function in the optimization procedure. The definition of "social welfare" is depicted in Figure 1.

Social welfare equals the sum of import and export area welfare. The dotted surface areas in Figure 1 illustrate two individual welfare values. Social welfare is therefore the area between supply and demand curves used in an auction clearing process.

The rectangle marked with a diagonal pattern is an area which represents the product of the quantity of the price-difference bid with its price. The price-difference bid replaces the social welfare in the optimization of the objective function where its surface is greater than the social welfare resulting from the organized/exchange market bids.

If there were no price-difference bids and no congestion, the exchanged quantity would be Q. Due to limitations in interconnections capacities the maximum allowed exchanged quantity is Q_{max}. In the case presented in Figure 1, Q_{max} is higher than Q so in principle the entire quantity could be exchanged. Irrespective of the "potential" Q, the following relation must always hold: $Q \leq Q_{max}$.

The objective of the optimization procedure is to find the combination of energy exchanges among areas that would bring the highest profit to the common system, taking into consideration the limitations in transmission capacities. Geometrically, the rectangle of the price-difference bid is placed "with its right side to the Q_{max}." From that point of view the optimization process evaluates when its surface is grater than the social welfare and its acceptance results in greater total welfare. The outcome is the exchange quantity Q' which is the quantity of energy exchange based on aggregate supply and demand curves from the organized/exchange market. The remaining exchange (till Q_{max}) results from price-difference bids.

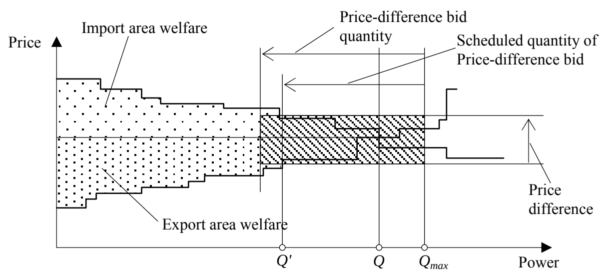

Fig. 1. Graphical evaluation of import and export area welfare and price difference bid.

4 The Optimisation Program

The optimization algorithm uses an objective function that represents welfare as a result of inter-area transactions of hourly products, including block products [5]. The function equals the maximum difference between import and export segments of net-export curves of all systems (areas within a congested system). The function also takes into account the price-difference bids (e.g. for transmission of electrical energy from bilateral contracts), and in that way presents an innovative solution of the decentralized market coupling method.

In Equation 1, C_{nik-u} stands for the price of the import segment k of net-export curve in area i within hour u. On the other hand, C_{pjh-u} stands for the price of the export segment h of net-export curve in area j within hour u. p_{ik-u} and p_{jh-u} are the quantities defined by the import and export segments of net-export curves. Index r defines the number of areas that contain import segments, and s defines the number of areas that contain export segments in their net-export curves. Indices l, and m define number of import and export segments in selected area.

$$f = \sum_{u=1}^{z}\left(\sum_{i=1}^{r}\sum_{k}^{l_{i-u}} C_{nik-u}\, p_{ik-u} - \sum_{j=1}^{s}\sum_{h}^{m_{j-u}} C_{pjh-u}\, p_{jh-u} + + \sum_{g}^{t} C_{g-u} BP_{g-u} \right) = \max \quad (1)$$

The price-difference bids are included in the third part of Equation 1 with their prices C_{g-u} and quantities BP_{g-u}. Index t defines the number of price-difference bids.

Such a selection of state variables affects the constraints that have to be defined in order to keep the optimization solution inside the permitted area. The constraints are as follows:

- flows on all interconnections within bottleneck capacity (BC) limits,
- every segment of the net-export curve has the upper and lower bound values,
- total export (import) volume of a certain area cannot exceed the sum of all export (import) segments of net-export curves of that area,
- none of individual segments can be exceed by volume, and
- every transfer of energy between two areas has to be distributed among interconnections in the way, that they impact the loading regarding PTDFs.

The definition of constrains also takes into account the block products.

5 Optimisation Program Examples

In this section we present elementary examples that illustrate the basic functionalities of the described optimization program.

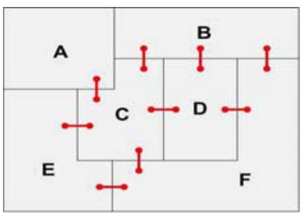

Fig. 2. Six areas network configuration used in examples.

To show the effectiveness of the program operation, we will observe, in turn, four different scenarios which will show: the basic optimization trading procedure, handling of transmission constraints, taking into account bilateral price-difference bids, and, finally, cross-product substitution. The region comprises six areas connected with nine interconnections as shown in Figure 2.

On account of simplicity, these four examples are based on the same selection of net-export curves of base load energy, thus only one parameter is changed or added in each example. The bids, or more precisely segments from which net-export curves of each area are built up, are presented in Table I.

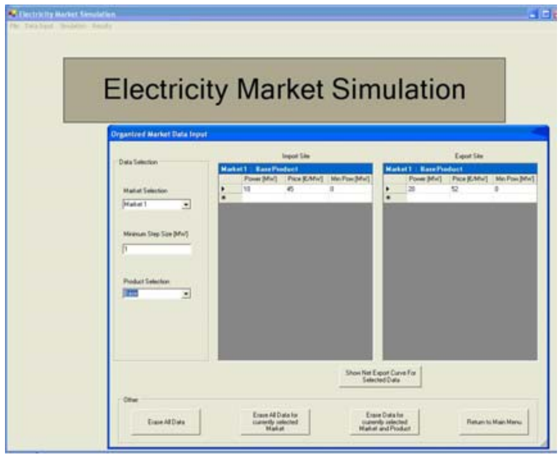

Fig. 3. Input window of the market simulation program.

Table 1: Segments of Net-export Curves of Product Base Load Energy

Area	Import		Export	
A	10MW@45€[1]		20MW@52€	
B			30MW@50€	30MW@53€
C	20MW@50€		20MW@55€	
D	30MW@53€	50MW@50€		
E	50MW@58€		5MW@65€	
F	10MW@40€		11MW@46€	

Four markets have the potential for both export and import while market B is "export only", and market D is "import only". All bids are for product base load.

5.1 No Network Limitations (Congestions)

In this case there are no transfer limits between areas, and the whole regional market acts as one area (market) – all BCs are set at 10.000 MW. Thus one market clearing price is given as a result. The example

[1] Segment 10MW@45€ represents 10 MW of product base load at a price of 45 €/MWh. (10 MW of base load = 240 MWh)

clearly shows the equivalence between the objective function and the area which is between import and export aggregate curves. Since no limitations exist, the exchange of electrical energy is realized in the most economical manner.

Areas A, B and F have the lowest prices defined with their export parts of net-export curves, thus the optimisation matches their offered energy with demand of areas D and E which offered the highest import prices.

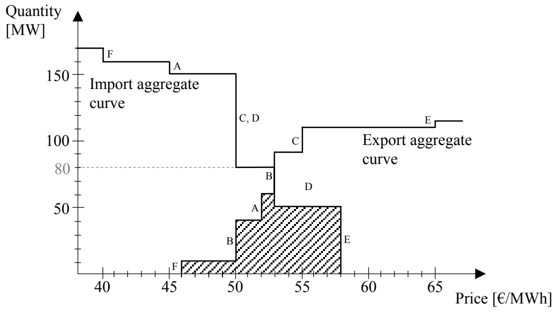

Fig. 4. Import and export area welfare.

The total trade is 80 MW of base load energy at a system price of 53 EUR/MWh. Due to the simplicity of the example it is possible to check that the algorithm does in fact include all possible trades. The power flows are illustrated in Figure 4.

Table 2: Optimization Results with no BC Limitations

Area	Result
A	SELL 20 MW @ 52 EUR/MWh
B	SELL 49 MW @ 53 EUR/MWh
C	(no trade)
D	BUY 30 MW @ 53 EUR/MWh
E	BUY 50 MW @ 58 EUR/MWh
F	SELL 11 MW @ 46 EUR/MWh

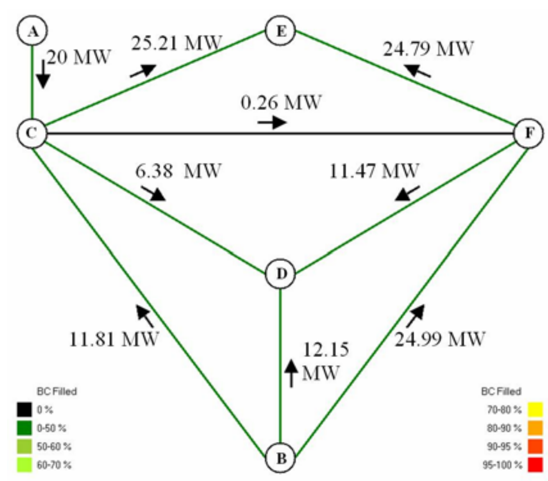

Fig. 5. The power flow of the network with no limitations.

5.2 Bottleneck Capacities Limited to 20 MW

In this example, we consider the possibility of cross-border congestion by setting all bottleneck capacities (BC) among all areas at 20 MW. As expected, the resulting exports and imports are different from exports and imports in example A, since BCs are limited and the load flow among areas and "bid matching" is calculated by means of PTDF factors. These factors define the path of energy between two areas; therefore different conditions affect the load flow. The trade in this case fell from 80MWh to 69 MWh as shown in Table III (changes are bolded).

Table 3: Optimization Results with BC = 20 MW

Area	Result
A	**SELL 19 MW @ 52 EUR/MWh**
B	**SELL 39 MW @ 53 EUR/MWh**
C	(no trade)
D	BUY 30 MW @ 53 EUR/MWh
E	**BUY 39 MW @ 58 EUR/MWh**
F	SELL 11 MW @ 46 EUR/MWh

If one interconnector which supports part of the load flow between two areas was limited to zero, it would at least in theory mean that these two areas cannot exchange their energy, even if this BC has the lowest percentage of load flow defined by PTDFs. This means the exchange is defined by the weakest interconnector in the region.

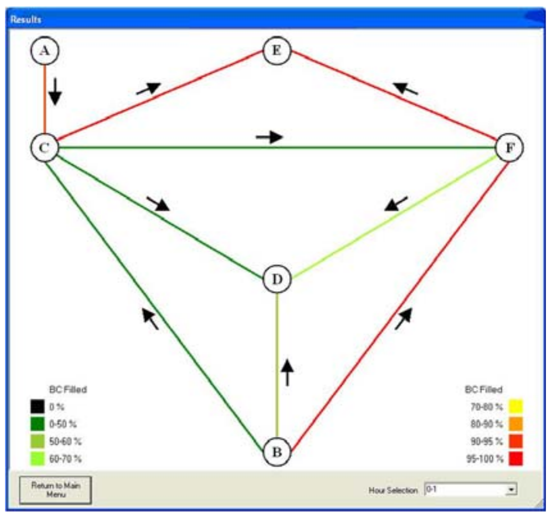

Fig. 5. The power flow of the network with BC = 20 MW.

Table 4: Interconnector - % of BC Filled

Interconnector	% of BC filled
A – C	93.2
B – D	53.6
B – F	100
C – E	100
C – F	2.1
C – D	35.7
C – B	44.4
F – D	60.7
F – E	96.4

5.3 Price-difference Bid for Transfer Capacity

In this example we continue from example B. A price-difference bid (all-or-nothing) for transmission of 20 MW of base load energy from area A to E is entered with a price of 10€/MW. This means that an applicant is willing to pay 10€ per MWh for transferring the energy between areas A and E (i.e. bid for cross-border capacity and not for energy).

The price difference between these two areas was 6€/MWh in the previous case (A: 52€/MWh, E: 58€/MWh). Thus the interconnector capacities are allocated to the price-difference bid which also takes over all the capacity between areas A and C. Consequently, no energy from the net-export curve is exported from area A. On the other hand, area C receives 1 MW of energy which is now “free” and area C’s price of 50 EUR is the best possible import bid available, taking congestion into account. Results are shown in Table V (changes are bolded).

This case clearly shows that if the price-difference bid offers a higher price than the implied “organized market” economic value of interconnectors between two areas, the capacities are allocated to that bid.

Table 5: Optimization Results With Added Price-Difference Bid

Area	Result
A	**SELL 20 MW (BILATERAL)**
B	SELL 39 MW @ 53 EUR/MWh
C	**BUY 1 MW @ 50 EUR/MWh**
D	BUY 30 MW @ 53 EUR/MWh
E	**BUY 20 MW (BILATERAL) + BUY 19 MW @ 58 EUR/MWh**
F	SELL 11 MW @ 46 EUR/MWh

With this example we also presented that it is possible to allocate the transmission capacities to energy from the power exchange and energy from bilateral contracts at the same time. This version of *implicit auctioning* delivers a more competitive (market) method of allocation of cross-border capacities, since it allocates all the capacities to the energy from power exchange and from bilateral contracts at the same time. This offers a nondiscriminatory way of allocation while the capacity is valued in one moment in time. This also helps to avoid the difficulty of splitting the BCs into two parts, one for the power exchange and the other for bilateral contracts.

5.4 Cross-product Optimised Matching

It is well known that standard electricity products can be substitutes – e.g. one could buy a combination of peak load and off-peak load products instead of base load. Therefore, any algorithm aiming at optimizing the transactions in view of maximizing the social welfare should take this into account.

To show the performance of the algorithm, hourly products were added to the basic case from example A. Hourly products from 1st to 24th hour altogether correspond to a base load product. For each hourly product 10 MWh were offered in area A at a price of 30 €/MWh. Thus for each hourly product one net-export curve is entered.

The price of these products is favourable compared to other prices in the market. Therefore, the expected result is for them to substitute 10 MW of the most expensive base load export. As shown in the results provided by Table II, in the basic case scenario area B exports 49 MW of base load product, but when net-export curves for hourly products were entered, the export from area B was reduced to 39 MW (as shown in Table VI). Other exports and imports of base load product were unchanged.

Table 6: Optimization Results With Hourly Products

Area	Result
A	**SELL 10 MW HOURLY @ 30 EUR/MWh and SELL 20 MW @ 52 EUR/MWh**
B	**SELL 39 MW @ 53 EUR/MWh**
C	(no trade)
D	BUY 30 MW @ 53 EUR/MWh
E	BUY 50 MW @ 58 EUR/MWh
F	SELL 11 MW @ 46 EUR/MWh

6 Acknowledgment

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