Implementation aspects of partial netting in flow-based auction clearing mechanism

Milan Vukasovic[1], Mladen Apostolovic[2], Christian Todem[1]

[1] Verbund - APG AG, Vienna, Austria
Wagramer Straße 19, IZD Tower
1220 Vienna, Austria
Phone: +43 (0) 50313-56154
E-mail: milan.vukasovic@verbund.at
christian.todem@verbund.at

[2] Energy Financing Team d.o.o., Belgrade, Serbia
Bulevar Mihaila Pupina 10b/II
Phone: +381 (0) 11 3011-031
11070 Belgrade, Serbia
E-mail: mladen.apostolovic@eft-group.net

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***Abstract*--The allocation of cross-border transmission capacities is a basic precondition for cross-border electricity trade. Insufficient transmission capacities are the factor that limits this trade and therefore they must be allocated in the economically efficient manner in order to alleviate its negative influence on the trade but along with the preservation of electric power system stability. The flow-based coordinated auctioning method introduces economic criteria for selection of requests for transmission capacities use when those requests exceed available amounts (congestion), along with a better representation of cross-border electricity transactions influence on transmission network. With the use of internet development tools, web simulator has been created, which allowed practical implementation and testing of coordinated auctioning method, especially a possibility to apply netting of counter-flows. Several sensitivity analyses and case studies have been conducted and the results that show the advantages of application of netting principle are elaborated.**

I. Introduction

THE interconnected control areas, managed by the Transmission System Operators (TSOs), gradually became zones with the high level of electricity transactions between them. Power flows over the cross-border tie-lines connecting those zones have to be limited to the maximal allowed value, related with the system stability and thermal limit of lines. Congestion that exists on specific cross-border interconnection is a clear indication of its economic value, and the entire procedure known as Congestion Management consists of market-based payment for the allocation of transmission rights to participants who those scarce capacities value the most.

In the flow-based coordinated auctioning method, auction for transmission rights is simultaneously organized on all cross-border interconnections, i.e. electrical borders between zones. Bids that consist of the requested power and a bid price are submitted in the pairs (from one source/input zone to another sink/off-take zone, which are not necessarily adjacent). The influence of each electricity transaction on every electrical border respectively is calculated using PTDF (Power Transfer Distribution Factor) matrix. For each electrical border, in both directions, technical limits that represent constraints on physical flow over aggregated tie-lines on that border (Border Capacity) are calculated. Optimization process, consisting of acceptation/rejection of bids, is solved using classic Linear Programming routine. This is, in fact, a well known problem of optimal allocation of scarce resources from the optimization theory. In order to maximise social welfare, scarce transmission capacities should be allocated to the market participants who are ready to pay the highest price for their usage. Maximisation of the total auction income is not the goal on its own [1], as it could be misconceived, but only the instrument which helps that the efficient allocation of scarce transmission rights is accomplished.

The flow-based coordinated auctioning method for the explicit allocation of transmission rights is described in the second chapter of this paper, with the description of the technical parameters necessary for the calculations (PTDF matrix, *BC*s) and definition of optimization problem. Coordinated Auction Simulator (CAS), developed with the use of PHP and MATLAB, is described in the third chapter. By means of CAS, several simulations of coordinated auctioning are conducted with respect to the application of netting principle by Coordinated Auction Office (CAO) in the clearing process, but also by the auction participants during the bid submission. First of all, sensitivity analysis is conducted to see how change in transmission capacity on borders influences the auction results, and later on, how application of netting principle affects those results. If the netting principle (rights-with-obligations) is to be applied, flows against the direction of active constraints are regarded as creating additional transmis-

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sion capacity. The auction participants are even able to adjust their bidding behaviour and to choose freely their netting factor. In that way, TSO has information to which extent it can rely on the contract from the auction participant. After the clearing process, in the case with netting, some auction participants are even able to receive a part of collected auction income rent. Case studies results show that use of partial netting in the flow-based coordinated auction leads to higher social welfare: a higher level of overall accepted bid power on regional level, better usage of transmission network and lower clearing prices. The advantages of application of netting principle for TSOs, but also for auction participants, are clearly highlighted in conclusions.

II. Description of The Coordinated Auctioning Method

Novelties that are introduced by the flow-based coordinated auctioning method for the explicit allocation of cross-border transmission rights [2], in comparison to bilateral methods (widely applied on the borders between EU countries) and also coordinated but based on ATC values (applied for number of years in the Central Europe [3]), are the ways of modelling of transmission network through Power Transfer Distribution Factors (PTDF) and Border Capacities (*BC*).

A. Power Transfer Distribution Factor (PTDF)

Power Transfer Distribution Factors represents a variation in the active power flows on the observed lines, which are a consequence of change of generation in specific pair of nodes in Electric Power System (EPS). Extension of this concept to the variation of power flows as a consequence of change of generation in pair of zones in EPS, in order to get zonal PTDF matrix, is not the most accurate approach since zonal PTDFs are sensitive to the node in the zone where change of generation takes place [4]. A practical calculation of PTDFs in direction from the zone X to the zone Y is done by increase of generation in so called PV (Power-Voltage) nodes in the zone X and simultaneous decrease of generation in PV nodes in the zone Y for the same amount in MW. In that way, additional electricity exchange between the zones X and Y is simulated. Change of generation in both systems is done in PV nodes, proportional to engagement of each power plant in the initial base case [5]. PTDFs are calculated on the mathematical model of EPS by means of specialized software for load-flow calculation and with the usage of lossless DC load-flow, which for this appliance has a number of advantages over the AC load-flow. PTDFs are dependent on the current network topology and parameters of electric power network elements. The quotient of variation of active power flows (ΔPF) on tie-lines on a border (ε) and power of electricity transaction (PT) from the source zone X to the sink zone Y, which induced that variation of power flows, is PTDF on the observed border for that source-sink pair:

$$PTDF_{X\to Y,\varepsilon} = \frac{\Delta PF_{\varepsilon}}{PT_{X\to Y}} \tag{1}$$

B. Border Capacity (BC)

BC („Border Capacity“) value, which represents calculated physical transfer capacities of the tie-lines on the border between two individual TSOs, limit physical power flows over those lines. The fundamental difference between currently widely applied restrictions to cross-border trade (Available Transfer Capacity - ATC) and the one in the coordinated auctioning method (*BC*), is that ATC represents maximum allowable sum of the power of all commercial electricity transactions accepted and after that, nominated for the realization over the border, while *BC* represents maximum allowable physical active power flow over the tie-lines on that border [6].

C. Optimization Problem

The objective of the coordinated auctioning is the allocation of scarce transmission capacities in such a way that social welfare is maximized, while network security limits should not be breached. The Criterion for the selective acceptance of the requested electricity cross-border transactions is the ration between the bid price and PTDF of that transaction on the congested border, which means that the bids with higher bid price and lower corresponding PTDF have priority. Mathematical formulation of this optimization problem can be written as follows:

$$\text{Maximize:} \quad \sum_{X\to Y,b} C^{b}_{X\to Y} \cdot PT^{b}_{X\to Y} \tag{2}$$

$$\text{Subject to:} \quad BC_{\varepsilon-} \le PF_{\varepsilon} \le BC_{\varepsilon+} \tag{3}$$

where: b – bid identification, $X\to Y$ – source-sink combination of an electricity transaction, ε – aggregated tie-lines on the border, $PT^{b}_{X\to Y}$ – allocated transmission source-sink right to bid b (MW), $C^{b}_{X\to Y}$ – bid price of bid b for source-sink pair $X\to Y$ (€/MWh), PF_{ε} – total power flow over aggregated tie-lines on the border ε, and $BC_{\varepsilon+}$ and $BC_{\varepsilon-}$ – Border Capacity at the border ε in forward and reverse direction, respectively.

The total active power flow over aggregated tie-lines on the border denoted as ε, induced by the accepted electricity cross-border transactions, can be written by means of PTDFs as:

$$PF_{\varepsilon} = \sum_{X\to Y,b} PTDF_{X\to Y,\varepsilon} \cdot PT^{b}_{X\to Y} \tag{4}$$

If no-netting or partial netting is to be applied, (4) has to be modified in order to account separately for the netable and non-netable flows, but in a slightly different manner than proposed in [7]:

$$PF^{NET}_{\varepsilon} = \sum_{X\to Y,b} PTDF_{X\to Y,\varepsilon} \cdot PT^{b}_{X\to Y} \cdot NF^{b} \tag{5}$$

$$PF^{no-NET}_{\varepsilon+} = \sum_{X\to Y,b} \left\{ \frac{1}{2}\left(\left| PTDF_{X\to Y,\varepsilon} \right| + PTDF_{X\to Y,\varepsilon} \right) \cdot PT^{b}_{X\to Y} \cdot \left(1 - NF^{b}\right) \right\} \tag{6}$$

$$PF^{no-NET}_{\varepsilon-} = -\sum_{X\to Y,b} \left\{ \frac{1}{2}\left(\left| -PTDF_{X\to Y,\varepsilon} \right| - PTDF_{X\to Y,\varepsilon} \right) \cdot PT^{b}_{X\to Y} \cdot \left(1 - NF^{b}\right) \right\} \tag{7}$$

where NF^{b} is netting factor of submitted bid b with possible values in range of [0,1], and $PF_{\varepsilon+}{}^{no-NET}$ and $PF_{\varepsilon-}{}^{no-NET}$ are non-netable flows in forward and reverse direction, respectively. Finally, one gets the following equations that should be included as constraints on the optimization problem:

$$\left(PF_{\varepsilon}^{NET} + PF_{\varepsilon+}^{no-NET}\right) \leq BC_{\varepsilon+} \tag{8}$$

$$BC_{\varepsilon-} \leq \left(PF_{\varepsilon}^{NET} + PF_{\varepsilon-}^{no-NET}\right) \tag{9}$$

Apart from the previous constraints, the following, trivial constraint also has to be taken into consideration:

$$0 \leq PT_{X\to Y}^{b} \leq \underline{PT}_{X\to Y}^{b} \tag{10}$$

where $\underline{PT}^{b}_{X\to Y}$ is total requested transmission source-sink right in bid b (MW).

The final set of equations, which is needed for solving Linear Programming optimization problem, is given by (2) – objective function, and (8)-(10) – constraints. Remuneration from the successful auction participant after clearing process is done by the means of shadow prices (SP_{ε}) associated to each transmission constraint (BC_{ε}). The shadow price represents variation of the objective function with respect to marginal increase (1 MW) of transmission constraint, and clearly indicates the economic value of the transmission capacity on each border. It should be noticed that "no congestion – no payment" principle is implicitly applied because the increase of border capacity on non-congested borders (non-active constraint) will not bring any variation of objective function, and consequently shadow prices for those borders will be zero. The final price which will be paid by the all successful auction participants with transactions from the zone X to the zone Y is given by the formula:

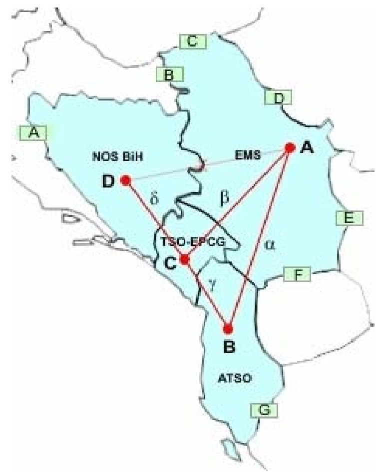
$$C_{X\to Y} = \sum_{\varepsilon} PTDF_{X\to Y,\varepsilon} \cdot SP_{\varepsilon} \tag{11}$$

III. CAS – Coordinated Auction Simulator

The developed simulator is based on the widely used programming package MATLAB, in which central optimization algorithm is coded, and user interface is developed as internet application. Before the auction for bid submission is opened, the system administrator which acts as CAO inputs in the system the basic data needed for the auction: PTDF matrix and Border Capacity values. Each registered auction participant is authorised by user name and password to submit bids via the Internet at precisely specified time period for particular auction. Bids consist of the requested period for transmission right reservation (hour, day, month, year), source-sink zone pair for desired transaction (only bilateral electricity transactions are considered), requested power (in MW) and bid price (in €/MWh). After the time period for bid submission expires, the CAO runs auction clearing process, and thus determines the accepted bids (fully or partially), total auction income, and the costs and eventual revenues for each auction participant.

A. Simulation of Flow-Based Coordinated Auction by Means of CAS Tool

The test system which is used for modelling and simulations represents a part of South-East European electric power system and is shown on Fig.1a). The interface towards non-modelled part of SEE region is denoted with letters A-G.



$$PTDF = \begin{array}{c} A\to C \\ B\to C \\ D\to C \\ A\to B \\ A\to D \\ B\to D \end{array} \begin{bmatrix} \frac{1}{3} & \frac{2}{3} & \frac{1}{3} & 0 \\ -\frac{1}{3} & \frac{1}{3} & \frac{2}{3} & 0 \\ 0 & 0 & 0 & -1 \\ \frac{2}{3} & \frac{1}{3} & -\frac{1}{3} & 0 \\ \frac{1}{3} & \frac{2}{3} & \frac{1}{3} & 1 \\ -\frac{1}{3} & \frac{1}{3} & \frac{2}{3} & 1 \end{bmatrix}$$
$$\qquad \alpha \quad \beta \quad \gamma \quad \delta$$

a) b)

Fig. 1. a) 4-zone SEE test system used for simulations, and b) corresponding PTDF matrix for the given test system

In the given test system, there are 4 zones and 4 electrical borders between them. The existing tie-lines on the electrical border between the zones A and D are considered to be out of operation, e.g. for maintenance. Dimensions of overall PTDF matrix are 12 x 4 (12 possible combinations of source/sink pairs, and 4 electrical borders) and because of symmetry property of lossless DC power flow which is used for its elements calculation [8], only a half of this matrix is shown in Fig.1b).

The initial simulation is performed over a set of 12 bids from several auction participants (electricity traders) that are given in Table I, together with the auction results. In Table II, Border Capacities (*BC*) of the test system are given, assuming to be the same for both directions over one electrical border, as well as power flows over tie-lines on those electrical borders and the percentage of border capacities usage. The *BC* usage of 100% indicates that congestion is present on that border.

TABLE I: Set of bids and auction results with the netting factor of 1.0 (100%) and the same forward and reverse border capacity (*BC*) values

Bid ID	Bid source/ sink	Bid price [€/MWh]	Requested capacity [MW]	Allocated capacity [MW]	Auction clearing price [€/MWh]
DB-no.1	DB	8.5	100	0	10
CB-no.2	CB	7	30	30	4
CD-no.3	CD	2.5	20	20	-6
AC-no.4	AC	4	150	101	4
CB-no.5	CB	5	10	10	4
AB-no.6	AB	3.5	50	0	8
DA-no.7	DA	2	150	105	2
DC-no.8	DC	6.5	50	50	6
DB-no.9	DB	10	50	34	10
AC-no.10	AC	4.5	75	75	4
AD-no.11	AD	1.5	20	20	-2
BC-no.12	BC	2.5	15	15	-4
		Total:	720	460	-

TABLE II: BORDER CAPACITY (*BC*) VALUES AND POWER FLOWS OVER INTERCONNECTIONS

Border and Direction	Border Capacity [MW]		Power Flow [MW]		BC usage (%)	
	forward	reverse	forward	reverse	forward	reverse
A>B	50	50	50	-50	100	-
A>C	100	100	40	-40	40	-
B>C	150	150	-9	9	-	6
C>D	150	150	-150	150	-	100

B. Influence of Change of Border Capacity Values on Auction Results

Netting factor in this analysis is held on the constant value of 1.0 (100%). It means that nomination of allocated transmission rights is obligatory. Border Capacity (*BC*) in direction from the area A to the area B is gradually increased during the simulation process, from 10 MW to 200 MW. A change of *BC* value can be caused by transmission network reinforcements (e.g. investments in construction of the new tie-line) or by the planned maintenance work.

As it can also be seen from Table I, certain submitted bids (CD-no.3, AD-no.11 and BC-no.12) have negative price after the clearing process and, accordingly, they create additional transmission capacity for trade. Those transactions are totally accepted and rewarded, i.e. a trader is able to make a profit even when he trades with the transmission capacity and not just with the electricity. Congestion is present in directions A>B and D>C, and submitted bids are accepted up to the point when calculated limit imposed by *BC*s on those binding profiles has been reached.

In Fig.2 it can be observed that, with the increase of *BC* value in the direction from area A to area B, successive increase of the total auction income is attained. Maximal value of the total auction income is reached for 125 MW *BC* value in the direction from A to B (in the amount of 2400 € with the congestion present on the following bordering profiles: A>B, A>C and D>C). Further increase of *BC* value in the direction from A to B would lead to reduction of the total auction income, since the congestion is relieved on the reinforced border (A>B), but it is still present on the two other critical interfaces (in directions A>C and D>C).

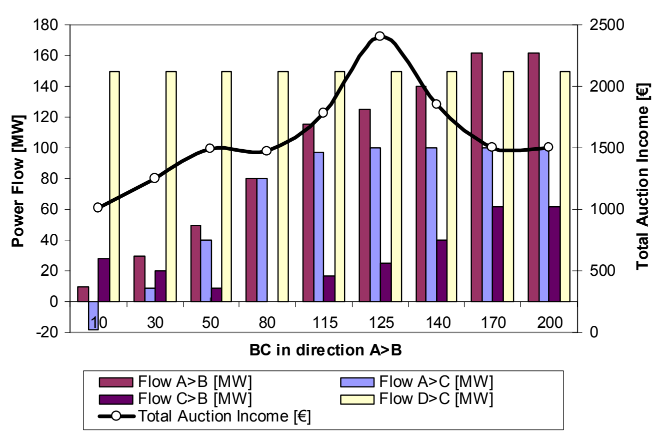


Fig. 2. Change of the total auction income and power flows over the border interfaces of modelled region in relation to *BC* value change in direction A>B

C. Change of Netting Factor Used for the Auction Clearing

The same bidding behaviour of traders (Table I) has also been used for this analysis, but in this case *BC* values on all borders are held on the constant level during simulation process and the netting factor used for auction clearing has been changed in constant steps of 0.1, from 1.0 (100%) – full netting to 0.0 (0%) – no netting at all. Netting has a positive influence on the total volume of allocated power (Fig.3). Namely, due to the fact that rights-with-obligation have been used for allocation procedure (traders must nominate capacity obtained on the flow-based coordinated auctions), electricity transactions that have source/sink pair in a commercially "less-interesting" direction will produce additional transmission capacity, i.e. will net flows from the opposite direction. Non-linear curve that depicts the ratio between the amount of total allocated power and netting factor shows robust decrease of average clearing price after the netting factor of 0.5 has been reached. A reason for this lies in the existence of the negative auction clearing price for the bids in the direction of trade which relieve congestion. Due to the above-mentioned fact, average price which is paid for inter-areas transmission capacity (interconnections) usage has been decreased. In the actual analysed case, an average price for 1 MW of the allocated transmission capacity is in range from 3.24 €/MWh to 5.1 €/MWh and the amount of the total allocated power is in range from 460 MW to 235 MW. In this simple example, a positive effect that netting can have on the better usage of transmission system and increase of the social welfare is clearly emphasised. The influence of netting could be regarded as an artificial enlargement of present *BC* values, which was previously discussed, but the actual enlargement could be done only by construction of new lines on the proper locations in a network.

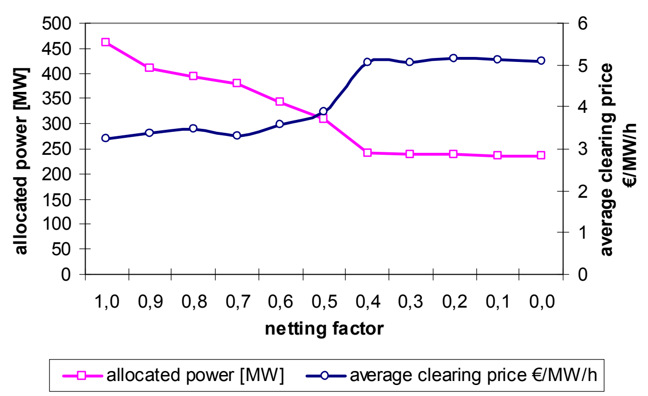


Fig. 3. Influence of netting factor on the total allocated power and the average clearing price paid for 1 MW of allocated power

IV. CASE STUDIES: FREE CHOICE OF NETTING FACTOR BY THE AUCTION PARTICIPANTS

Developed CAS tool deals with netting factor in range of [0,1] for each bid separately, but while it is possible to make such an auction clearing algorithm, it would be necessary to reconsider a possibility for introduction of such a feature especially from the auction participants' point of view. Namely, with the implementation of this proposed concept, traders would be able to choose freely a suitable netting factor for their electricity transaction, from 0 (no netting at all) to 1 (full netting). For example, consider the case when the auction participant wants to submit capacity bid for 50 MW in the trading direction from A>B with the price of 5€/MWh and the netting factor of 0.8. The same bidding behaviour of auction participant would be achieved if two bids with the different power/netting factor pair were submitted: 40 MW bid with the netting factor 1 (rights-with-obligations) and 10 MW bid with the netting factor 0 (rights-without-obligations). But from the market perspective, a trader will probably not use the same bidding behaviour, i.e. he will evaluate higher bid which is an obligation for him and therefore he will be ready to offer higher price (i.e. 6€/MWh) for the first bid and lower price for the second bid (i.e. 1€/MWh). In this case, two bids with the different offered prices will be submitted to the auction system. Furthermore, a bid with the netting factor between 0 and 1 can be interpreted as two totally independent bids: one with the netting factor 1 and the other with the netting factor 0. Therefore, due to the above-mentioned reasons, only the bids with the netting factor 1 or 0 are considered in the following analysis (the netting factor different from these values can be easily represented by the combination of two of them, as it is showed above). To illustrate this, one of the original bids will be divided into two independent bids with the same offered price, but with the different netting factors (0 and 1) and results will be discussed further on.

In four analyzed case studies, a set of 8 bids from several auction participants is considered. The basic bid data, including netting factor of each bid, altogether with allocated transmission capacity after clearing process is given in Table III. The border capacities offered in the auction and their associated shadow prices for each case study are given in Table IV.

As it is shown in Table III, maximal network usage and therefore social welfare, is reached in the case when all submitted bids are rights-with-obligations (**case study 1**). Namely, the highest volume of transmission rights with the source-sink type is allocated to the different auction participants, the lowest market clearing prices are reached (there is no congestion in the modelled system and therefore "no-congestion, no-payment" principle is in force). The total auction income collected by the CAO in case study 1 is zero. In the second analyzed scenario, **case study 2**, two submitted bids (AD-no.5 and BA-no.6) are rights-without-obligations, i.e. options. After the auction clearing process, all submitted bids are accepted as in case study 1, but due to the higher network uncertainty, first of all caused by bid BA-no.6 which is an option in this scenario, the border capacity between areas A and C can be used in the worst case up to the maximal offered value (100 MW) and, therefore, congestion may occur. Market clearing prices are different from zero and two obligatory bids DA_1-no.7 and DA_2-no.8 which relieve flow over critical bottleneck, are rewarded (market clearing price for this direction, according to (11) is $-2/3 \cdot 0.978$ €/MWh = -0.652 €/MWh). In the third analysed scenario, **case study 3**, two bids with different netting factor for transaction from the zone D to the zone A are submitted: one bid - DA_1-no.7, as firm (obligation, NF=1), and another - DA_2-no.8 as non-firm (option, NF=0). This leads to decrease of the total accepted power for bid BC-no.4 from 50 MW to 38 MW caused by congestion on the border interface A>C (with shadow price 3.000 €/MWh). However, two submitted bids (DA_1-no.7 and DA_2-no.8) with the same offered price and the same source-sink combination have different market clearing prices

TABLE III: BIDS AND AUCTION RESULTS FOR THE ANALYZED CASE STUDIES

Bid ID	bid source/sink	Requested Capacity [MW]	Bid price [€/MW/h]	Case Study 1		Case Study 2		Case Study 3		Case Study 4	
				Allocated Capacity [MW]	NF	Allocated Capacity [MW]	NF	Allocated Capacity [MW]	NF	Allocated Capacity [MW]	NF
AC-no.1	AC	50	3	50	1	50	1	50	1	50	0
AC-no.2	AC	50	2,5	50	1	50	1	50	1	50	0
BC-no.3	BC	50	2	50	1	50	1	50	1	50	0
BC-no.4	BC	50	1	50	1	50	1	38	1	30	0
AD-no.5	AD	10	3	10	1	10	0	10	0	10	0
BA-no.6	BA	30	2,5	30	1	30	0	30	0	30	0
DA_1-no.7	DA_1	4	0,5	4	1	4	1	4	1	4	0
DA_2-no.8	DA_2	6	0,5	6	1	6	1	6	0	6	0
Total accepted power / Total auction income:				250 MW / 0 €		250 MW / 97.83 €		238 MW / 300 €		230 MW / 243 €	

TABLE IV: BORDER CAPACITIES AND RELEVANT SHADOW PRICES

Border and Direction	Border Capacity [MW]		Case Study 1		Case Study 2		Case Study 3		Case Study 4	
	forward	reverse	shadow price forward	shadow price reverse	shadow price forward	shadow price reverse	shadow price forward	shadow price reverse	shadow price forward	shadow price reverse
A>B	50	50	0	0	0	0	0	0	0	1.138
A>C	100	100	0	0	0.978	0	3.000	0	1.861	0
B>C	150	150	0	0	0	0	0	0	0	0
C>D	150	150	0	0	0	0	0	0	0	0

due to the fact that one bid is optional while the other is obligatory (Fig.4). Both bids are totally accepted in the auction clearing process but only bid DA_1-no.7 which is an obligation has the right to receive part of the total auction income collected due to the congested network by the CAO. It is important to notice that, since bid DA_2-no.8 is an option in this case and PTDF of this bid is positive on relieving congestion on the border interface A>C, bid BC-no.4 which has the lowest ratio between bid price and PTDF on congested interface, have to be partially rejected, i.e. total accepted power of this bid is decreased for 12 MW (from 50 MW to 38 MW). With the different combinations of submitted netting factors and formation of the different case, it is easy to prove that the total accepted power after the clearing process will always be located between minimal 230 MW (**case study 4** - all submitted bids are options) and maximal 250 MW (case study 1 - all submitted bids are obligations). However, the total auction income can be significantly higher in those cases in comparison to 243 € collected in case study 4 (case without netting). It is clearly showed that netting factor of only one submitted bid can have high influence on the final market clearing prices and even produce two different prices for the same trading direction.

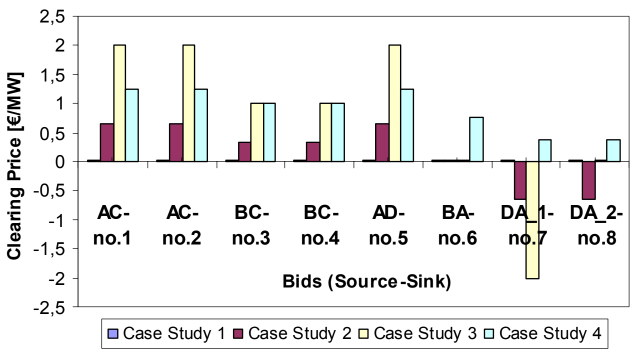


Fig. 4. Market clearing prices for the analyzed case studies

V. Conclusions

The general principles of the European regulation state that the maximum transmission capacity of the interconnectors affecting cross-border flows shall be made available to the market and that TSOs shall net capacity requirements in the opposite directions in order to maximise capacity as far as possible, taking into account technical and network security standards.

From the TSO perspective, the coordinated flow-based mechanism for allocation of transmission rights leads to the better forecast and control of power flows inside interconnection, i.e. lower variance between nominated flows using PTDF matrix and real power flows on the actual day when physical delivery of electricity takes place. This fact is of the crucial importance for TSOs which have as one of the main goals under deregulated environment to preserve the secure and reliable operations of the high-voltage transmission network. On the other hand, the coordinated flow-based method is more complex for electricity traders and wholesale electricity suppliers than ATC-based explicit auction and therefore those market participants should have proper incentive to start using this methodology. Partial netting, i.e. a possibility for the auction participant to obtain a part of the money from auction income fund, if he chooses an appropriate netting factor for his (successful) auction bid, could be such an incentive.

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VII. Biographies

Milan Vukasovic (b. 1981) received his DI degree and M.Sc. in Electrical Engineering from University of Podgorica, Montenegro (2004 and 2007). He works in Verbund APG (Austrian Power Grid) AG – Market Management Department (UMM). His main interests are in electricity markets modeling and simulation, congestion management and computer applications in power systems. He is a member of Central Eastern Europe Work Group Coordinated Auction (CEE WG CA) and Pentalateral Work Group (Commercial Task Force – CTF).

Mladen Apostolovic (b. 1975) received his DI degree and M.Sc. in Electrical Engineering from University of Belgrade, Serbia (2000 and 2005). Presently he works in Energy Financing Team – Portfolio Management Department. Previously he has worked with Electricity Coordinating Center (2001/05) and Electric Power Utility of Serbia (2005/07). His topics of research include congestion management methods, power systems security and deregulated electricity markets.

Christian Todem holds a Master degree in electrical engineering and a PhD in energy economics, both from Graz University of Technology (TU Graz) in Austria. He is currently employed by the transmission system operator VERBUND-Austrian Power Grid AG and is responsible for market development. Dr. Todem is a member of different international TSO working groups and is a convenor of a TSO working group for developing and implementing flow-based coordinated auctions.