Flow-Based Coordinated Explicit Auctions: Auction Income Distribution

Florian Leuthold and Christian Todem

Abstract—**The development of adequate market-based congestion management methods in continental Europe lags similar developments elsewhere, e.g. in the US. To achieve greater integration of the single European market, the EU countries were grouped into seven regions, one of which is Central East Europe (CEE). Based on publicly available data, a flow-based coordinated auction for this region is modeled and simulated to demonstrate different auction income distribution schemes. The model is a linear optimization problem which is solved in GAMS. It is based on a zonal model of CEE including 8 zones and 13 tie-lines.**

We show that the auction income distribution schemes as defined by the European Transmission System Operators (ETSO) in 2001 do not provide proper incentives. Additionally, the most efficient auction income distribution scheme differs with the chosen market structure. Therefore, an allocation procedure that is based upon the estimated flows according to the bids accepted appears to be an appropriate trade-off for all of the cases included in our analyses.

Index Terms—**Congestion management, power system economics, power transmission economics**

I. INTRODUCTION

When vertically integrated electric utilities predominated, the congestion management mechanisms then in use attempted to minimize generation costs and network losses while guaranteeing high levels of network security [1]. In the course of deregulating the electricity sector however, congestion management also underwent significant change. While the Transmission System Operators' (TSO) primary task is still network stability they no longer influence the location of generation. Instead, the liberalized energy market decides which provider will best satisfy the existing demand. Accordingly, the TSOs can only define a framework and prepare the appropriate actions that will achieve sufficient network security [1]. In Europe, market liberalization has to some extend facilitated cross-border electricity trade; one important example is the establishment of energy exchanges for standardized products. Also, price differences between different EU countries provide an economic incentive for increased trading. The fundamental reason for the price differences consists in the different age structures, generation technologies and locations of the EU countries' plants. Increased trading and the scarcity of transmission capacities within control areas require coordinated cross-border congestion management tools that account for the physical impacts resulting from these situations. Flow-based coordinated explicit auctions are one such mechanism.

This paper focuses on the incentive effects of the income allocation of explicit auctions. A brief overview of congestion management methods is given (Section II) and auctions for transmission rights are briefly introduced (Section III). Since the flow-based coordinated explicit auction is planned to be applied in a realistic environment, evaluation criteria are defined to represent the necessary tasks (Section IV). Section V introduces the mathematical model and the data set, and the different auction income allocation schemes. These methods are examined for their incentive compatibility to the set of targets defined for an applicable congestion management scheme (Section VI).

We show that the auction income distribution methods proposed by ETSO in 2001 [2] are not incentive compatible according to the targets defined in our paper. We also find that a better trade-off comes from allocating income according to the flows resulting from the bids accepted. Moreover, our analysis shows that the perpetuation of technical profiles – as combined border capacities – is inefficient, and that the auctioning of obligations appears to be superior to the auctioning of options.

II. BRIEF SURVEY OF CONGESTION MANAGEMENT METHODS IN A EUROPEAN CONTEXT

In general, one can distinguish between flow-based and non flow-based congestion management. Non flow-based methods assume that electricity can be transported from one specific location to another in the grid. In reality, however, each input spreads over the entire meshed network. Flow-based

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methods respect the grid's physical specifics. The optimal network usage is calculated by means of demand and willingness to pay based upon physical constraints.

Among the flow-based methods, the most suitable congestion management method is nodal pricing (compare i.e. [3 - 5]) which considers each node within the network separately. The price for energy at a node represents the incremental cost incurred for delivering one more MWh of energy to that node, and therefore is the best scarcity signal. Because nodal prices normally vary between different nodes, each node is in effect its own marketplace.

Another congestion management method is zonal pricing which employs either of two approaches: market splitting or market coupling. The market splitting approach assumes an existing integrated market where injections and withdrawals of several nodes are assigned to a specific zone (hence, there is only one energy price per zone). Zones can be interpreted as sub-markets that, ideally, form according to network congestion [6]. The difference between market coupling and market splitting consists in differing starting conditions [6]. The market coupling approach, in contrast, assumes that sub-markets already exist and cannot be merged into one integrated market in the short or medium term, and therefore attempts to interlink these sub-markets.

Coordinated explicit auctions also attempt to interlink different markets; the difference between the approaches mentioned above consists in the chronologies of the market clearing process and the traded commodities. The first step of an explicit auction is the allocation of transmission capacity, followed by opening the electricity market [6] so that the required quantities can be bought and transmitted according to the awarded transmission rights. Coordinated explicit auctions can be either flow- or non flow-based.

III. AUCTIONS FOR TRANSMISSION CAPACITY

An auction is an instrument to find a price for a good if the value is not at all or incompletely known [8]. Most of the existing literature on auction theory focuses on single, indivisible goods. Transmission capacity, however, does not fit this category. In a flow-based coordinated explicit auction, several winning bidders may receive different shares of the total auction capacity while every bidder pays the same price for the same transaction (an auction where all bidders pay the same price is called a uniform-price auction [9]). In our model, the last accepted MW is curtailed to the marginal bidders. Hence, the auctioned good (transmission capacity) becomes divisible. According to [10], "the literature on the sale of multiple units is much less well developed […]."

IV. FROM THEORY TO PRACTICE: WHY FLOW-BASED COORDINATED EXPLICIT AUCTIONS?

Although nodal pricing is already applied in several markets around the world, implementation in Europe in the near future appears unrealistic because of the different market structures (including pool structures as well as bilateral markets) now in place. The first studies based on a nodal pricing approach - carried out for European regions indicate positive economic effects (compare [11 - 13]). Nonetheless, one problem is the high degree of complexity that may lead to problems with both market transparency [14] and liquidity [6].

Political divergence is also an issue. The different degrees of market liberalization within the EU-states and the existence of many established system operators, each responsible for one control area, constrain the implementation of nodal pricing in Europe. Some experts recommend [7] that a flow-based coordinated explicit auction – and further developments towards flow-based market coupling – is the most likely congestion management method under present regulatory conditions. Other political issues are examined in [15].

In addition to political considerations, there are also technical issues. At the moment, there are net transfer capacity (NTC)-based methods applied throughout Europe but these auctions are not flow-based and do not take into account physical realities (see Appendix).

Last, the economic framework in the EU must be considered. There is a high demand for electricity in Southern Europe – mainly in Italy – combined with a generation surplus in Northern Europe. In addition, there are energy price differences from North to South and from East to West Europe. Consequently, there is an economic incentive for interregional trading activities, yet energy transport is restricted by the transmission capacities between single countries and regions. The EU lacks a single market system that could incorporate the varied existing market structures but still move all players toward eventual integration.

We conclude first that a flow-based market system is crucial to achieving an efficient resource allocation within the EU. Second, the market must be structured to incorporate different schemes such as explicit and implicit auctions. Third, the transition to integration will likely be step by step to accommodate the range of political considerations. We suggest that the first step is the introduction of a flow-based coordinated explicit auction.

V. ASSUMPTIONS, OBJECTIVES AND METHODOLOGY

A. *Assumptions*

This paper assumes that a TSO desires to maximize its individual auction income and has an economic incentive to change its border capacities (BCs) to accomplish this desire. Each income of a TSO – including auction income – will be treated as a regulated income. Hence, our assumption does not contradict Regulation 1228/2003 on cross-border trading.

We also assume that a TSO is able to stipulate BCs independent from the other TSOs and is able to change them, i.e. for network security reasons.

With these assumptions in mind, an income allocation method is favorable if it stimulates the TSOs – through respective individual auction income allocation – to set their BCs close to or equal to the thermal limit. Technical necessities can likewise be incorporated by adjusting physical thermal limits using a (n-1)-security margin.

B. *Objectives*

1) *Incentive signals*

The objective of this analysis is to evaluate the incentive mechanisms of different auction income distribution schemes in conformity with the requirements suggested below. We begin with the two distribution schemes proposed by ETSO in 2001 [2], and hypothesize that these two methods (see Section IV.C.3) sent incorrect signals regarding capacity provision and network utilization to TSOs and the market. We define the requirements for an applicable incentive scheme as follows:

1) Giving incentives to each TSO for an efficient resource utilization – providing maximal BCs.
2) Create a stability of auction income for TSOs compared to currently applied methods (in terms of limiting volatility for a transition period).
3) Allocating income according to the correct scarcity signals to indicate the necessity of network investments at appropriate locations. (At the same time, TSOs need incentives to actually invest in extensions.)
4) Aligning with the regulatory requirements of the EU and national regulators.

2) *With or without netting: options or obligations*

There are two types of physical transmission rights. Owning an obligation means that one is obliged to use the right. If the right is not used, a compensation payment is charged. In this case, netting of opposite flows can be taken into account. Thus, flows over the same line with different signs cancel out one another.

Owning an option means that one has the right to decide whether to actually cause a flow. A compensation charge does not apply if the transmission right is not used. Thus, in the case without netting flows over the same line with different signs do not cancel out because the risk of overstepping technical parameters cannot be excluded. Netting cannot be considered when owning an option.

3) *Excluding/including combined border capacities*

Existing schemes include technical profiles (TP). Technical profiles pool several borders and define an aggregate sum BC for them. This paper refers to TPs as Combined Border Capacities (CBC). We analyze how the TPs currently used affect the results of the flow-based auction if perpetuated as CBCs.

C. *Methodology*

1) *Procedure*

We first establish a flow-based coordinated explicit auction. The input data is chosen from real data (see Section IV.C.6) and the auction results are calculated for all considered cases (Table 1). The calculations are the reference bases for further analysis.

Next, the border capacities for single borders are varied in steps of 50 MW or 100 MW, depending on the expected effect of the change, and the auction results are recalculated until a change in income allocation does not occur or is no longer significant. The changes of BC are carried out ceteris paribus. The considered outcomes are, consequently, the incomes of the TSOs that changed the BC as well as the impact of these changes on the total auction income (TAI) and on the incomes of all other TSOs. The results presented focus on a change of the BC for one border between two TSOs (referred to as TSO1 and TSO2).

The results yield additional information (such as the TAI and the percentage share of accepted to requested bid volume) that can be used to analyze the effects on netting and the inclusion of CBCs.

TABLE 1
CASES CONSIDERED IN THE ANALYSIS

	Excluding CBCs	Including CBCs
With netting	Case 1	Case 2
Without netting	Case 3	Case 4

2) *Mathematical formulation and auction algorithm*

Mathematically, the auction algorithm or clearing process is a constrained optimization problem as shown in equations (1) to (5). The objective function is the overall auction income subject to the capacity restrictions of the tie-lines.

This mathematical formulation is similar to one proposed by ETSO [2]. The network includes *Z* zones that are linked by interconnections. There are *B* bids. Auction bids must contain the following information: the bidding path, price and quantity. Hence, price p and volume d_{bid} can be written as functions of bid $b \in B$, source $x \in Z$ and destination $y \in Z$: $p(x,y,b)$ and $d_{bid}(x,y,b)$. The clearing process provides the accepted volumes per bid $d_{bid}(x,y,b)$. The network is represented by a PTDF matrix *R*. The elements $r \in R$ reflect the impact of the bid volumes for a specific pair of zones in terms of flows on an interconnection represented by its source zone $x \in Z$ and sink zone $y \in Z$. Hence, element r depends on source x, destination y, and interconnection j-k: $r(x,y,j,k)$. The optimization problem can be written as:

$$\max\left\{\sum\nolimits_{X,Y,B}[p_{bid}(x,y,b)*d(x,y,b)]\right\} \qquad (1)$$

$$\text{s.t.}\quad d_a(x,y,b) \le d_{bid}(x,y,b) \qquad (2)$$

$$d_a(x,y,b) \ge 0 \qquad (3)$$

$$\sum\nolimits_{X,Y}\left\{r(x,y,j,k)*\sum\nolimits_{B}[d_a(x,y,b)]\right\} \le BC\_F(j,k) \qquad (4)$$

$$\sum\nolimits_{X,Y}\left\{r(x,y,j,k)*\sum\nolimits_{B}[d_a(x,y,b)]\right\} \ge BC\_R(j,k) \qquad (5)$$

Where: x = zone as source of a bid
y = zone as sink of a bid
b = bid within the auction
j = zone as source of a tie-line
k = zone as sink of a tie-line
BC(j,k) = border capacity between zone *j* and zone *k* for Forward (F) and Reverse (R) direction
$d_a(x,y,b)$ = accepted quantity per bid
$d_{bid}(x,y,b)$ = required quantity per bid
$p_{bid}(x,y,b)$ = bid price per bid
r(x,y,j,k) = element of the PTDF matrix (zone-to-zone notation)

Within the clearing process, a merit bid price order per source-sink combination is generated. Additionally, the maximum resulting flow per tie-line is received by the sum of all bid volumes multiplied by the respective PTDFs. If there are lines where the resulting flow is greater than the available border capacity, the requested bid volume must be decreased until the flow capacity constraints are fulfilled. The transaction with the lowest willingness to pay for a congested line is decreased first, the bid with the second lowest willingness is considered next and so on – until the constraints are fulfilled and the overall auction income is maximized.

If there is no congestion, no market player is charged (i.e. no congestion, no payment). If there is congestion, some transactions will be decreased as described above, and all of the transactions that “win” in the auction will be charged according to their PTDF and marginal price for congested borders. The last accepted bid (partially or totally) defines the marginal price (i.e. this “marginal” bid will pay its bid price). Other accepted transactions will be charged on the basis of the bid price of the marginal bid (= marginal price) but multiplied by the ratio of their PTDF and then divided by the PTDF of the last accepted transaction at the congested border.

3) Auction income distribution methods[1]

a) ETSO1

The income is allocated to the TSOs that are sources or sinks of bids. One can interpret this as distributing the income according to supply and demand zones. Hence, the accepted bid volumes for each source-sink combination are multiplied by the respective prices. These incomes per combination are distributed in equal shares to the source and sink TSOs.

$$ETSO1(x) = \frac{\sum_{B,Y}\left[p_a(x,y)*d_a(x,y,b)\right]}{TAI}$$

where: $p_a(x,y)$ = accepted bid price per bid path
$d_a(x,y)$ = accepted bid volume per bid path

An analog equation applies for the ratio for sink zones *y*.

b) Shadow Prices (= SP, ETSO2)

The sum of all shadow prices is calculated and then the individual share of the shadow price of a line is determined with respect to the sum of shadow prices. The income is allocated according to these shares and distributed equally to the TSOs owning the line.

$$ETSO2(j) = \sum_{K}\left[\frac{\mu(j,k)}{\sum_{J,K}\mu(j,k)}\right]$$

where: $\mu(x,y)$ = marginal price per line

An analog equation applies for the ratio for sink zones *k*. This is also true for the following methods.

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[1] For a more extensive formulation see [15].

c) *Absolute Flow Fraction (= AF)*

The share of a tie-line flow with respect to the sum of all line flows is calculated. Then the income is allocated proportionally to these shares and equally to the TSOs owning the line.

$$AF(j) = \frac{\sum_{K} ABF(j,k)}{\sum_{J,K} ABF(j,k)}$$

where: ABF(*j,k*) = flow resulting from accepted bid volumes

d) *Clearing Price (= CP)*

The clearing prices for each line can be calculated by multiplying the shadow prices by the PTDF. The absolute flows are then multiplied by the absolute clearing prices. Next, the sum of these weighted flows is calculated, and the individual share of a line with respect to the weighted sum is determined. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

$$CP(j) = \sum_{K} \left\{ \frac{\left| p_C(j,k) * ABF(j,k) \right|}{\sum_{J,K} \left[\left| p_C(j,k) * ABF(j,k) \right| \right]} \right\}$$

where: p_C(j,k) = clearing price per line

e) *Relative Flow Fraction (= RF)*

The ratio of border flow to border capacity is determined which yields the relative line usage. All line usages are totaled and the share of individual line usage with respect to the sum of line usages is calculated. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

$$RF(j) = \sum_{K} \left\{ \frac{\left[ABF(j,k) / BC(j,k) \right]}{\sum_{J,K} \left[ABF(j,k) / BC(j,k) \right]} \right\}$$

f) *Thermal Usage Fraction (= TU)*

The ratio of border flow to thermal limit is determined, which yields the thermal limit usage. All thermal limit usages are totaled and the share of individual thermal limit usage with respect to the sum of usages is calculated. The income is allocated according to these shares and equally distributed to the TSOs owning the line.

$$TU(j) = \sum_{K} \left\{ \frac{\left[ABF(j,k) / TL(j,k) \right]}{\sum_{J,K} \left[ABF(j,k) / TL(j,k) \right]} \right\}$$

where: TL(j,k) = thermal limit of a line

g) *Physical Flows*

It is also possible to distribute the income according to the actual physical flows. Although these flows can be measured and the incomes distributed ex ante, we note that no consistent data set is available. On the other hand, since the proportion of outside and natural flows is currently quite high, the physical flows do not correlate sufficiently with the flows resulting from the auction, and therefore, any incentive schemes are distorted.

TABLE 2
ANALYZED INCOME ALLOCATION METHODS

Method	Allocation according to
ETSO1	100% Bid Zones
SP (ETSO2)	100% Shadow Price
AF	100% Absolute Flows
CP	100% Clearing Price
RF	100% Relative Flows
TU	100% Thermal Usage

4) *Evaluation criteria for auction income distribution methods*

We selected four criteria (defined in Section V.B.1) for evaluation purposes. For each case, we calculated the incomes per TSO in absolute and in relative numbers (auction income shares). Additionally, we rated some criteria for absolute incomes and income shares. We then merged the two ratings to find the absolute income and relative income results.

a) *Resource utilization incentives*

Incentives should exist for TSOs to provide as much installed capacity as possible. Hence, an income distribution method is favorable if the incomes and income share of the TSOs responsible for a BC change are positive when increasing BCs, and negative when decreasing them.

b) *Network investments*

Whether a method is likely to foster network investments by TSOs or other market players will depend upon allocating income according to a scarcity measure (a price signal) or after the completion of n assumed grid extension. If the extension causes a decrease in income, the respective TSO might not have an incentive to invest.

c) Stability of incomes

The stability of income is defined by the maximum deviation D_{max} in income or income share respectively for all market players, while changing BCs. The deviations for TSOs should be somewhat comparable for political reasons.

d) Continuity with current auction income

The current auction income of TSOs results mainly from NTC-based coordinated explicit auctions or bilateral auctions. As mentioned above, setting BCs equal to NTCs causes some distortions in the risk of actual flows; the absolute auction incomes from the NTC-based allocation should not be compared with the absolute auction income from a flow-based allocation. Therefore, for the continuity with current auction income, only income shares are compared in cases when BCs equal the present NTC values. Since we assume that a positive deviation in income share is considered positive by all market players, only the maximum negative deviations are considered.

5) Evaluation criteria for netting and CBCs

Other tools analyze the effect of netting the perpetuation of CBCs. First, the percentage of total accepted bid volumes allows us to measure the degree to which the existing demand can be satisfied. The TAI can be interpreted as the cost of congestion. Additionally, the measure of income per accepted volume (RPV) is introduced, which is the ratio of TAI divided by the accepted bid volume in absolute numbers. The goal is to meet the greatest possible demand at the TAI level.

6) Data

The data set focuses on Central East Europe (CEE) where real information was easily obtained. Some simplifications were made in calculating BCs and the PTDF matrix. Losses are excluded since they are the responsibility of each control area. Transmission costs only depend on the costs of congestion in the form of the auctioned physical transmission right (compare [16]). If there is no congestion, the transmission is "free" – the TAI is then zero.

a) Border capacities

Border capacities are calculated based on a common grid model The TSOs are required to exchange programs and relevant data which are then merged and the border capacities calculated accordingly.

These data has not been made public so our analysis assumes that the NTC values for 2006 are the same as the BC values (Source: References [17] and [18]). Note that this causes distortions if one tries to compare NTC and flow-based results. We also applied the 2006 NTC-based auction data for the cases including CBCs. (Source: Reference [17]).

b) PTDF matrix

The PTDF matrix is the representation of the physical network. The PTDFs are based on a DC power flow approximation of the network.[2] They are coefficients that describe the relationship between a bid volume and the resulting flow on a tie-line. PTDFs are often called sensitivity factors [1] since they describe the sensitivity of accepted bid volumes to line flows.

There are two different notations for a PTDF matrix. First, the PTDF value can be calculated with respect to a global hub (Fig. 1). This hub can be a zone within or without the considered network. The result will be the same since the numbers are now relative in respect to the hub.

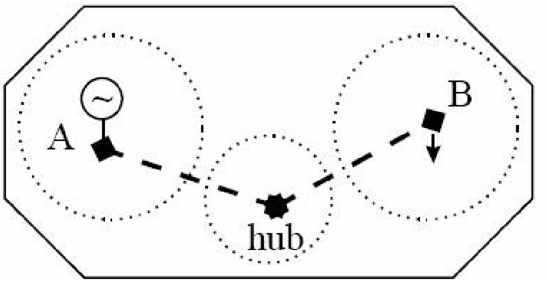

Fig. 1. Zone-to-hub network

Second, the PTDF matrix can be written in a zone-to-zone notation (Fig. 2). Every possible combination for a transaction between each two zones and their sensitivity factors on each line is listed explicitly. The zone-to-zone matrix value for a connection can be calculated by taking the zone-to-hub PTDF value of the source to the hub and adding the PTDF value for a transaction from the hub to the sink. Calculating this for each pair of sources and sinks yields the zone-to-zone PTDF.

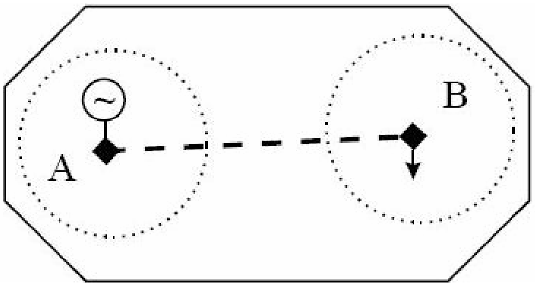

Fig. 2. Zone-to-zone network

Our analysis maps the 8 zones and 13 tie-lines in the CEE region to give a reliable PTDF matrix. Each control area defines one zone in the analysis. The surrounding UCTE grid is modeled as a ring

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[2] For instructions about using the DC Load Flow model in economic analyses, see [3, 12, 19].

grid. However, the PTDF matrix is determined based on an empty grid.

c) Bids

To receive a reliable data set for the demand, the available public data for the NTC-based coordinated explicit for five zones within the CEE region are considered [17]. The demand is represented in increments of 5 MW and the respective prices. For the rest of the CEE region, approximately 1500 bids for the yearly bilateral auctions are used (Source: [17] and own estimations).

VI. RESULTS

Note that this section presents the results that were obtained from the large set of data created by the analyses (see [15] to retrace the results by means of the explicit numbers).

A. Auction income distribution methods according to the ETSO from 2001

1) ETSO1

This method distributes the income to the TSOs that are source and sink of bid. Congestion is likely to occur elsewhere. Surprisingly, this does not negatively affect resource utilization in the cases excluding CBCs. Here, incentives are awarded to increase BCs. However, the method is unfavorable for the cases including CBCs. More important, however, is the fact that network investment issues are not taken into account. There are no scarcity signals where network investments are the most urgent nor does it generate an appropriate return on investment. TSOs that are source and sink of a congested connection do not receive the payments (and may even have negative incomes) but instead pay to maximize the total auction income (and network usage) in cases with netting. Since the TSOs cannot influence the demand for transmission capacity, negative incomes may extend for several periods.

Total auction income and income shares do not deviate negatively for the cases with netting, but they differ strongly for the cases without netting. The continuity with current incomes is given for case 3 only.

2) Shadow Prices (= SP, ETSO2)

This method assigns incomes only to lines that have a shadow price – where congestion occurs. TSOs have an incentive to set BCs so that they are source or sink of a congested line. There is no incentive to increase BCs because this will lead to decreasing auction income if the congestion is relieved. This becomes evident for the cases without netting. For cases 2, 3, and 4, TSOs clearly have an incentive to lower BCs.

For the cases with netting, there is a slight incentive to increase BCs in case 1. The explanation is that even though both TSOs relieve congestion on one line by increasing BC, congestion on other lines in which they participate becomes more serious and balances the income loss from the first line. This only occurs for case 1 since other restrictions such as CBCs or the ignorance of netting do not apply. In this method the auction incomes are distributed to the locations where investments are most urgent, but there is no real incentive to invest in transmission capacity which may relieve a congested interconnection permanently. Total auction income and income shares do not deviate negatively for the cases with netting, but they differ strongly for the cases without netting.

B. Additional auction income distribution methods

1) Results for cases with netting

a) Resource utilization incentives

Considering resource utilization incentives, the optimum rating for the cases with netting is given to method TU which assigns incomes according to the usage of the lines' thermal limits. It appears favorable from the point of view that the thermal limit is a physical parameter that cannot be changed voluntarily. In method AF, however, only resulting bid flows (= accepted bid flows, ABF) are considered. For this method, there is no real incentive to lower BCs to create congestion because this results in reduced flows and lower incomes. TSOs are also incented to provide maximum capacity because it will lead to stagnation or increased incomes. (Particularly when excluding CBCs there is an incentive to increase BCs). In method CP, the ABFs are weighted with the clearing prices for the respective connection. For the cases with netting, TSOs are not incented to withdraw capacity from the market.

In contrast, method RF distributes incomes to those lines that have a high usage of their BCs. For the cases with netting, it appears that this creates an incentive to set the BC so that the expected usage is close to 100%. Hence, there is an expected optimal BC for each line that is far from the maximum capacity and oriented at the expected ABFs. We note that this method does not provide good incentives for the efficient allocation of resources.

b) Network investments

Method AF lacks a scarcity (price) signal to indicate where investments are most urgent. On the other hand, an extension of the grid to relieve congestion does not automatically reduce incomes. If an investment leads to higher flows, incomes increase and there is no reluctance to invest in new line capacities. Method CP, however, has a scarcity signal. Tshese price signals are not as strong as the shadow prices weighted with the PTDFs; relieving congestion may change the set of shadow prices but does not withdraw the entire incomes because there is still a price based on all other shadow prices. The clearing price may decrease but the ABF may increase. The reluctance to invest can be considered low.

In method TU, an extension of the existing thermal capacity leads to a lower thermal usage and there is no incentive for TSOs to invest. On the other hand, Method TU may send appropriate scarcity signals if the BC is set close to the thermal limit. At the moment, this does not occur. A similar problem occurs in method RF, where network investment could occur for a line if the ABF is higher than the installed capacity. However, then the relative usage is already at 100% for a congested line.

c) *Stability or incomes*

The negative deviations in total incomes and income shares are low for most of the methods. The efficiency gain from netting and the netting effect appear to absorb effects that occur in the cases without netting. Incomes have a strong negative deviation only for case 2 and for method RF.

d) *Continuity with current incomes*

Only method AF can guarantee sufficient income adequacy.

2) *Results for cases without netting*

a) *Resource utilization incentives*

The results without netting differ significantly compared to the result with netting. Method TU, for example, only sets appropriate incentives for efficient network utilization for the cases with netting. The only method that can maintain its rating is method AF because it rewards the occurrence of higher ABFs, and there is still an incentive for higher BCs in order to create higher ABFs. For the other methods, this incentive is not given. For method CP and the methods including a share of CP or SP, there is an incentive to create new congestion rather than increase BCs. One explanation is that if netting is not considered, the volume of accepted bids is very low; only bids with a high willingness to pay can be accepted. Consequently, the incentive to create expensive congestion is high. Again, method RF creates an incentive to set the BC so that the expected usage is close to 100%. We conclude that there is an expected optimal BC for each line that is far less than the desired maximum capacity.

b) *Network investments*

The results are the same as for the cases with netting (see Section VI.1)).

c) *Stability of incomes*

The results differ significantly for the cases with and without netting. Without netting, there is no method that fulfills this target well. However, methods AF and RF show acceptable results. The negative deviations in total incomes and income shares are high for method CP. This is explained by the fact that for the same demand data the prices at congested borders tend to be higher in the case without netting. Relieving congestion, therefore, leads to higher prices. Further, there is no netting effect that can absorb this effect. As a consequence, incomes are much more volatile while changing BCs.

d) *Continuity with current incomes*

The results are the same as for the cases with netting; only Method TU shows better results. However, none of these results influence the overall rating.

C. *Further results*

Our research shows that for cases with netting, the accepted bid volumes are much higher (Fig. 3). The accepted bid volume– for all bids – with netting is between 67.92% and 74.87%. The accepted bid volume without netting is between 8.23% and 15.93%. This difference shows the effect of netting on the amount of demand that can be accepted. The additional available capacity through netting leads to more efficient utilization of the network. The netting effect works as follows. If bids are accepted that cause opposite flows over a line, resulting flows cancel out and the capacity is still available for further bids. Consequently, more bids – also with lower bid prices – can be accepted before the line flow constraints become binding. In addition, the RPV must also be considered.

Regarding the perpetuation of CBCs, the RPV is lower for the cases excluding CBCs than for the respective cases including CBCs (Table 3). While CBCs lead to a less efficient outcome, they cannot be justified from a technical point of view, either, as flow-based allocations reflect the physical network better than NTC-based allocation. Hence, this reasoning for CBCs is no longer valid.

TABLE 3
RPV FOR THE CASES WITH NETTING

		BC (TSO2_TSO1) [MW]			
		50	100	200	250
RPV	Case 1	65.6	65.6	65.6	65.6
	Case 2	74.1	74.7	74.5	74.5
	Case 3	304.1	328.8	340.4	332.3
	Case 4	425.2	492.0	458.8	390.8

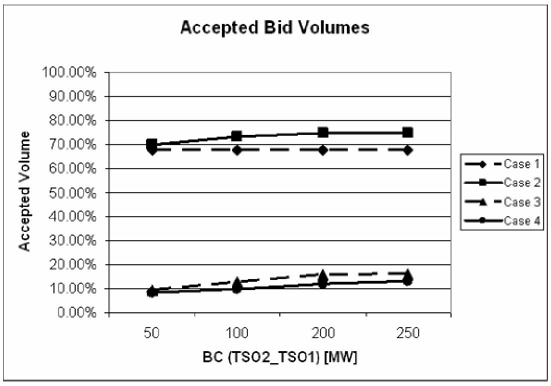

Fig. 3. Accepted bid volumes

VII. CONCLUSIONS AND PERSPECTIVES

In this paper, a flow-based coordinated explicit auction for the CEE region is developed and the results of different income allocation methods are analyzed. It is assumed that incentives to behave efficiently are awarded to TSOs via auction income distribution. In designing optimum incentives, it should be recognized that congestion management and market structure are politically sensitive issues throughout much of the EU.

Our analyses show that the auction income distribution methods proposed by ETSO in 2001 [2] are not incentive-compatible with the defined set of targets. In particular, method ETSO1 causes negative external effects for the case with netting that may lead to negative incomes for some TSOs. Method ETSO2 (SP) fails to set proper incentives concerning capacity provision thus affecting resource utilization.

It is important to research the inclusion or exclusion of CBCs and, if netting is allowed since the most favorable distribution method differs with such market conditions. Two methods define an acceptable trade-off: the first allocates incomes on the basis of the ABFs (Method AF). Therefore, even relieving congestion does not decrease incomes to the respective TSOs (i.e. incomes may stagnate but TSOs are not reluctant to increase BCs). The second weights the ABFs with the clearing prices for the respective tie-line (Method CP). Since the CPs are calculated on the basis of the shadow prices, this leads to greater volatility of incomes when changing BCs. Method CP itself is an interesting trade-off, particularly when the market structure will be defined to exclude CBCs and allow netting (case 1). In addition, evidence was found that the case with netting leads to a much higher network utilization and that the cost of congestion (TAI) is also lower.

The perpetuation of TPs such as CBCs tends to increase congestion costs and distort prices. The netting effect appears to compensate effects that occur more clearly in the cases without netting. The incomes, for instance, become less vulnerable to BC changes for many of the considered distribution methods. Consequently, if the actual market structure is defined, it may be helpful to reexamine some of the income distributions that are presently rejected.

The results of our analyses also suggest that policymakers and regulators clarify their expectations, i.e. the acceptable levels of volatility of incomes and incomes share because some evaluation criteria are only useful during the transition to full market integration. The flow-based coordinated explicit auction approach should be the first step, followed by the application of other market designs, the introduction of financial transmission rights [28], and the integration of power exchanges to create a hybrid auction mechanism.

APPENDIX

The variance in auctioned capacity and real flows can be large. For a three zones example (Fig. 4), consider when the NTC for borders A-B and B-C are zero but the NTC for border A-C is not. Thus, if the auctioned capacity for A-C is 100 MW, the occurring flow will also be 33.3 MW on A-B and B-C according to the PTDFs of the system (Table 4), although the auctioned capacity is zero for each of the two borders.

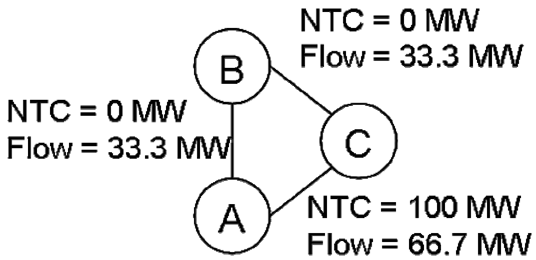

Fig. 4. Three zones example

TABLE 4
PTDF MATRIX FOR THREE ZONES EXAMPLE (ZONE-TO-ZONE NOTATION)

	A-B	A-C	B-C
A-B	0.667	0.333	-0.333
A-C	0.333	0.667	0.333
B-A	-0.667	-0.333	0.333
B-C	-0.333	0.333	0.667
C-A	-0.333	-0.667	-0.333
C-B	0.333	-0.333	-0.667

Currently, several TSOs apply so-called technical profiles (TPs), claiming that they mitigate or resolve intra-zonal problems. TPs pool several borders and define a sum NTC for all of them, i.e. all flows leaving a zone.

The TPs are considered in our analysis, where they are referred to as combined border capacities (CBCs) for the flow-based coordinated auction (compare [15]). It is expected that a flow-based method leads to higher BC values than NTC values for the same border and that the occurring physical flows are better reflected through a flow-based auction since loop flows are not accounted for in the NTC-based allocation. Hence, the variance of possible occurring flows (σ1 > σ2 in Fig. 5 and Fig. 6) is less in a flow-based allocation meaning that the risk situation also differs.

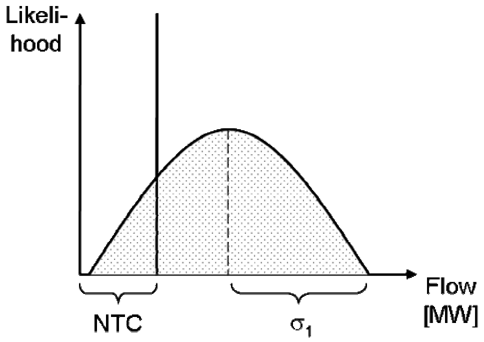

Fig. 5. Risk situation in an NTC-based method

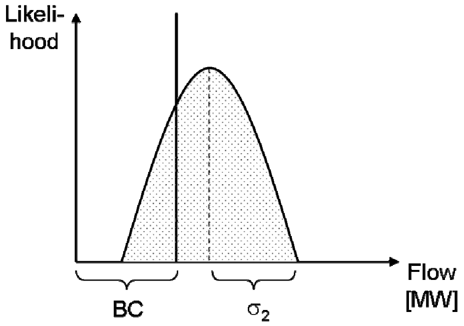

Fig. 6. Risk situation in a flow-based method

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