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Report

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Europe's power system in transition: How to couple zonal and locational pricing systems?

Report on key elements of the debate at the workshop “Nodal-Zonal Co-existence” of the Future Power Market Platform¹,

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1. Introduction

On the way to a low-carbon power system, dominated by variable renewable energy sources like wind and solar power and reduced conventional generation capacities, new flexibility options will be needed to balance demand and supply. Due to the high maximum power output, yet low capacity factors of intermittent renewable energies and the absence of a copper plate connecting the European continent, balancing will to a certain degree need to be done locally, even under ambitious grid extension plans. This brings new arguments and urgency to the established debate of introducing locational prices to integrate market clearing and congestion management (and the resulting efficiency and system security gains).

So far, grid constraints within pricing zones were mainly solved via administrative re-dispatch, i.e. via administratively determined adjustments of market results based on cost estimates of a few large conventional power plants. In renewables-based power systems, new flexibility options are emerging, for example flexibility in providing electricity-based heating and cooling to household and industry, various electricity and intermediate product storage options as well as electric vehicles, such that new options to provide local responses to grid needs are emerging. However, for all these options it is difficult to use the traditional approach of re-dispatching as the two basic requirements for administrative redispatch, (i) transparency of (opportunity-)costs (ii) robust base line for supply or demand, are not met. (Opportunity) costs of these (new) flexibility options vary across actors, are difficult to monitor externally, and vary over time with the state-of-charge of storage, or motivation to driving an electric vehicle at a given moment. Furthermore the hypothetical base line of supply/demand in absence of re-dispatch opportunities is difficult or impossible to determine. In such circumstances, administrative re-dispatch to respond to predictable congestion patterns is bound to induce large welfare losses.

Coordinating a large number of actors with diverse economic preferences calls for a market solution. Due to the physically introduced local component, this implies locational price signals. In order to avoid gaming opportunities, such price signals ought to be coherent over time, otherwise actors will for example avoid selling electricity in the day-ahead market and choose to be remunerated at the short-term locational (re-dispatch) market price, if wind- and solar generation patterns allow market

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participants to anticipate grid constraints and therefore profit from more attractive prices in the re-dispatch markets.

Due to historically grown power systems and institutions supporting them, different countries will feel the need (and willingness) to introduce locational price signals at different points in time and interested countries will argue that under subsidiarity, it is their choice to make. Their pre-existing network capacity, existing (and declining) flexibility options and preferences for market based congestion management versus administrative re-dispatch will determine whether they need to use locational prices to deal with transmission constraints. As in the long-term all countries will very likely require locational pricing systems to accommodate the increasing share of renewable energy and flexible demand side options, any early national implementation of locational prices offers a learning opportunity and potential blueprint for other countries, but poses the question how such locational marginal pricing (LMP, also called nodal) systems will interact within the existing European zonal power market approach.

2. Interface options for locational pricing and zonal systems

We discuss several, principal options to create an interface between zonal and locational pricing power systems. Their suitability for the different time frames is evaluated in the following section. The following options are discussed: First, auctions collecting supply and demand bids can facilitate coupling by solving for locational prices by integrating grid constraints in the clearing algorithm. Second, sequential zonal and nodal clearing can couple the markets as well, yet needs to address potential issues of misaligned incentives between the markets. Third, the system operator in locational pricing regions could pre-screen bids provided to common European platform, which is, however, unsuitable for a first market clearing and cannot take neighbouring grids' constraints into account. Lastly, the system operator in locational pricing regions can provide an aggregate supply function to the European system that aggregates individual demand and supply bids.

Auctions

In auctions several bids and offers for electricity (using potentially a set of bidding formats) are first collected, then the market is cleared at one price for each location (assuming uniform price auctions). This discreteness bring several features with it making it an especially suitable solution to couple zonal and nodal systems:

- The clearing algorithm can implicitly consider grid constraints (as is done already in a limited way in flow-based market coupling)
- It allows for matching of different product types (for example longer products, such as 60-minute products can be matched with products of shorter length, such as 15-minute products), including matching of multi-part bids⁴

⁴ Multi-part bids are offers by generators and demand, which can contain more components than simple price/energy pairs, such as different offer components (start-up costs and variable costs), as well as technical constraints.

- If grid constraints are to be respected, several individual trades may each be infeasible, while at the same time the combination of these trades can be simultaneously feasible. Matching such bids while respecting grid constraints requires auctions.

In addition, auctions also bring benefits to zonal systems (cf. the earlier workshop report on intraday auctions: Neuhoff, et. al., 2016):

- Auctions lead to a clear reference price also on shorter (intraday and balancing) time-frames (in contrast to continuous pay-as-bid trading), which allows for definition of future and other financial products without basis risk, thus facilitating contracting for flexibility
- Have larger market depth and liquidity for larger generation and demand adjustments
- Via allowing for several bid types (incl. multi-part bids) allow for clear expression of economic preferences of actors and can thus unlock full flexibility and provide fair remuneration.
- When they are unit-based, they ensure incentive compatible information on demand and supply for all locations, facilitating better forecasting of flows
- Auctions ensure efficient capacity allocation and pricing.

Zonal and nodal systems could either be integrated via a single auction algorithm, or via an iterative coupling of two separate auctions (such iterative algorithms exist for example to couple nodal-to-nodal systems, cf. Zhao et. al., 2014). Due to time-constraints in clearing, the market integration via a single auction mechanism would need to rely on:

- harmonization of bidding formats, and could be achieved by a shift to multi-part bids, as this could be represented as a mixed-integer problem, which is solved quicker than the combinatorial problem under the current block bid structure
- Introduction of minimum up-lift payments to avoid the algorithmic complexity linked to identification of paradoxical rejected bids in today's system (van Vyve, 2011)

Sequential zonal and locational pricing clearing

The nodal market could also be imbedded in a zonal market clearing. In this case there would be an adjustment (re-dispatch) market, following the zonal market clearing. Producers in the nodal market would thus participate in the European-wide zonal market clearing, and then sequentially in the nodal market which adjusts the dispatch decisions to consider grid constraints (in essence a redispatch market).

This approach performs is sub-optimal as compared to auctions and has the critical issue of misalignment of incentives across the time frames, leading to gaming opportunities, such as the inc-dec game (see box on the following page). Another issue is that in areas of high locational prices, generators will not bid into the zonal market with relatively lower prices, as they can receive a higher price in the local redispatch market (even without exercising market power which exacerbates the problem). This leads to a loss of liquidity in the zonal day-ahead market. Load, on the other hand, will gladly accept the (relatively) low zonal price, and might even overstate their demand if they can then receive a higher payment for reducing their demand in the nodal market.

These issues would need to be addressed by regulatory rules, as is for example done in Italy (in the ancillary services market (MSD), which is a locational pay-as-bid market and handles both redispatch, as well as balancing), and takes several mitigating measures (Oggioni & Lanfranconi, 2015):

- Italy is already split into several zones, reducing the price differences between the zonal and locational prices

Inc-Dec (Increase-Decrease) Game

If grid constraints can be anticipated, in order to be accepted producers in export-constrained areas reduce the price at which they offer power in the day ahead market. This can be profitable, because to relieve grid constraints they will need to be dispatched down. They keep the price difference between the lower locational redispatch price and the relatively higher zonal day-ahead price (or even being paid on-top in case of negative locational prices). Symmetric gaming incentives exist for load in load pockets. Thus the inc-dec game (i) increases the scale of transmission constraints, response measures and thus risks for the system (ii) creates the wrong incentives for location of generation in generation pockets and load in load pockets further increasing constraints. This game has, for example, played a role in the California Energy Crisis (Alaywan et. al., 2004) and led to issues in other zonal markets (Neuhoff et. al., 2011).

To reduce incentives for and scale of the inc-dec game, countries like Germany mandate re-dispatch and attempt to remunerate only at cost basis. This is, however, limited to generation assets for which base lines and costs can tracked more easily by third parties. It precludes the participation of demand side flexibility and storage in re-dispatch to help address transmission constraints, and thus also

- Unit-based bidding enables market power monitoring

It should be noted that when cost-based redispatch has issues of determining the exact cost-basis, the inc-dec game also exists in that if the cost are overestimated, similar incentives prevail.

Pre-screening of bids

The system operator of the locational pricing system could also pre-screen bids submitted to zonal trading systems, testing if these violate any transmission constraints. In order to assess the potential violation of transmission constraints, a good estimate of the current status of the transmission grid, as well as the impact of a single bid is needed, which makes this approach unsuitable for a first market clearing, or larger adjustments (as the impact is conditional on the acceptance of other simultaneously submitted bids). Impacts on feedback from trades with the transmission grid of neighbouring zonal systems (done for example via FBMC) can also not be considered in this solution. Experience with pre-screening of bids may be collected in development of European balancing platforms with reference to the “conversion” process to be implemented by central dispatch systems and the provision for “unavailable bids” pursuant to Article 29(14) of the GLEB. The main concerns regarding this approach related to transparency of TSO decisions and the strictness with which such a screening mechanism is applied:

- If the TSO is generous in pre-screening bids, bids are accepted that result in violations of transmission constraints, requiring further TSO action to resolve these, and may also create incentives for an inc-dec game.
- If TSO is restrictive in pre-screening, liquidity will be reduced.

It may be difficult to find a level of strictness that ensures sufficient integrity of the locational pricing system and of the European market integration. However, this approach is in line with the current paradigm and does not require zonal systems to implement any changes.

Aggregated import-export functions

An additional option is for the nodal system operator to act as an intermediary to the zonal system and aggregate supply and demand bids into import/export functions for a zone/country. The system operator can thus aim to ensure the non-violation of internal constraints when constructing the import/export curve. The bigger the variations around the base case within all regions are, the higher either the likelihood of violation of constraints or the lower the capacity that can be allocated. Hence the approach seems less suitable to act as an initial mechanism for coupling, as there is a higher uncertainty around the base case earlier in time.

One issue is that the export function is not locational specific – the same aggregate supply function would be provided to all neighbouring countries (the EU single clearing algorithm) - but the counter party to the net-trade would determine the impacts on local constraints. Lessons on how to handle this may be learned from implementation of balancing exchange mechanisms in central dispatch countries, as these will need to translate bids into the standard bidding formats (according to Article 27 of GLEB). The advantage of this approach is the compatibility with the current paradigm.

3. Market design steps to couple locational pricing with zonal systems

Several steps can be taken to facilitate a coupling of zonal and locational pricing systems in Europe. We distinguish here adjustments to market design at the day-ahead, the intraday and the balancing stage.

Day-ahead stage

At the day-ahead stage, only the first two options, an integrated solution via a common/iterative auction mechanism or a sequential zonal and nodal clearing are in principle feasible. The later options, bid-clearing and import/export functions, depend on an existing feasible schedule of production to work and are better suited for marginal adjustments, and can therefore be ruled out for the day-ahead stage.

The first-best solution would be an adjustment of Euphemia (or a shift to existing commercially available software packages), the common clearing algorithm in the PCR, to jointly clear the zonal and nodal systems in Europe in an auction (alternatively Euphemia could be coupled iteratively with the clearing algorithms of nodal systems). The advantages are

- that grid constraints in the nodal system, and those constraints considered in the zonal system (critical branches in FBMC) are simultaneously considered and thus a better utilisation of the system overall is achieved.

- Absence of a zonal price in the nodal system and resulting misalignment of incentives.

However, Euphemia in the current setting does not have the capacity to integrate a large number of additional nodes or to run several iterations. This could be resolved by a harmonization of bidding formats to multi-part bids (definitely unit-based for the locational pricing system) and a shift to minimum-uplift payments to avoid the complexity associated with paradoxically rejected bids and enforcing linear prices (Van Vyve, 2011). Thus the combinatorial challenge of solving for minimum income conditions, blocks including linked block orders, and exclusive group blocks would be avoided and the a shift to Mixed Integer Linear Programs (MILP) and non-linear pricing would accelerate the solution algorithm.

Alternatively, the day-ahead market could be solved sequentially at the zonal and nodal level. Market participants from the nodal system would participate in the Euphemia algorithm and then market results would be adjusted in the following national nodal market. As discussed previously, this would result in gaming opportunities and might lead to liquidity problems, as market participants would move into the sequential (nodal) markets to selectively profit from price differences. These would need to be addressed by regulatory measures. The need for such measures could be possibly reduced by introducing more zones in Euphemia for the nodal system, and thus reduce the differences between zonal and nodal market results, as well as further mitigation measures. As will be discussed in Section 4, such a shift to more zones is however not incentivised under the current system.

Intraday stage

At the intraday stage, auctions could play a pivotal role in the coupling of nodal and zonal systems, for the same reasons as at the day-ahead stage, while delivering additional benefits to zonal countries as well (Neuhoff et. al, 2016). As continuous trading is not compatible with the simultaneous calculation of nodal prices, intraday auctions are the most promising way to couple these systems.

In the Clean Energy Package (COM (2016) 863 final), intraday auctions are specifically discussed as a way to allocate transmission capacity at the intraday stage and there is an on-going discussion about the frequency of such intraday auctions. From a network point of view, any time a full update of the network representation takes place, an auction would ensure that this network capacity is fully utilised. However, in order to better integrate wind and solar power forecasts, more frequent auctions (especially in the nodal system) are needed, for example at an hourly interval. Here balancing the number of auctions with the issue of the need of many-to-many arbitraging between many auctions warrants further investigation. As with the day-ahead market an integrated solution is to be preferred over sequential coupling.

If the nodal system is obliged to participate in the continuous intraday market, two of the options seem (in principle) feasible: First, the system operator pre-clears all bids (which would need to happen very fast as not to disadvantage traders in the nodal system). The strictness of the clearing algorithm will determine whether a gaming of the system (loose clearing), or limited integration with the zonal system (strict clearing) will be the major risk. Second, market results that may violate internal constraints are periodically corrected in internal redispatch (e.g. as part of intraday auctions). This would however create all the incentives for the inc-dec game and its implications for efficiency and system security.

Balancing stage

Several mechanisms to allow for more exchange in the balancing stage are currently under development and are supposed to be finalised at different stages in the coming year(s) (GLEB, 2017). As this is a purely TSO-to-TSO interaction, nodal systems could in principle be fully integrated in the mechanisms under development.

Alternatively the European Balancing Guidelines (Article 27, GLEB, 2017) allow central dispatch operators to participate in the clearing of the cross-border balancing mechanisms via aggregating internal bids and offering them via import/export functions.

4. Incentives for more locationally-granular price signals under flow-based market coupling

Currently, countries are discouraged to increase the spatial resolution of their pricing zones (including integrating locational pricing in the auction mechanism), as they will forgo the priority that currently is granted to flows within zones over cross-zonal flows. This represents a hurdle to the integrated auction-based solutions of nodal-zonal coupling, as countries moving to a more granular representation of congestion would implicitly fully open their system to other countries (as all lines would be “cross-border” in Euphemia), while countries maintaining large zones have currently priority access to critical interfaces for their internal flows and may limit cross-border flows to reduce their national redispatch cost.

Recent discussions have aimed to ensure that countries open large parts of their cross-border capacity for trade, with mandatory opening of shares of 75% of available transmission capacity being debated. In principle, this could eliminate the incentive for countries not to reduce the size of pricing zones. Any pre-defined sharing of transmission capacity between flows within and cross-zonal flows will, however, inherently create inefficiencies as the value of transmission capacity for internal and cross-zonal flows is always varying. This re-emphasizes the ultimate benefit of locational pricing – ensuring that all transmission capacity is allocated to facilitate flows that minimize total system cost⁵.

⁵ Or more precisely, maximize social welfare if demand side bids are considered (as they should be).

5. Summary

We started the discussion based on the understanding that with increasing shares of intermittent renewables and therefore increasing importance of demand side flexibility, in a longer-term perspective locational pricing systems will be an important element of any power market design. This raised the question how the evolving European power market design and rules can create the opportunity for countries to gather and provide early learning experiences on the effective implementation of locational pricing.

We found that in principle multiple options exist, but most of them are characterized by inefficiencies and gaming opportunities and can only take partially account of transmission needs. According to all considered economic criteria, auctions are most suitable to interface between locational pricing and zonal systems in all time frames. Day ahead, intraday and balancing markets and congestion management should apply the same spatial resolution. All that may, however, require some regulatory adjustments at the European level that would need to be quickly assessed as part of the EU Clean Energy Package.

	Evaluation			Relevance for time frame			
	Internalisation & respecting network constraints	Gaming-Proof	Need for regulatory change	Day-ahead	Intraday-Auctions	Intraday-Continuous	Balancing
Auctions	+	+	-/o*	Yes	Yes		Yes
Sequential	-	--	+	Yes*	Yes*	(Yes*)	
Pre-screening	--	-	-/o **		Yes*	(Yes*)	Yes*
Aggregation	o/-	o	-/o ***		?		Yes*

* Gaming opportunities and/or inefficiencies

** "o" in case of existing unit based bidding / "--" in case of portfolio based bidding,

*** 0 in case of central dispatch / - in other markets

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