Technical Aspects of Nodal Pricing

CPI Workshop Report

Karsten Neuhoff
Rodney Boyd

Climate Policy Initiative Berlin

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Contact	karsten.neuhoff@cpiberlin.org

About CPI

Climate Policy Initiative (CPI) is a policy effectiveness analysis and advisory organization whose mission is to assess, diagnose, and support the efforts of key governments around the world to achieve low-carbon growth.

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Background

The expansion of renewable generation and closer integration of European power markets requires new tools and procedures for system operation. The US experience with nodal pricing offers options to tackle the emerging challenges, and thus may facilitate further integration of intermittent renewable generation technologies.

At a one day roundtable hosted by CPI Berlin, experts from European transmission system operators (TSOs) and international specialists explored the technical aspects of implementing and operating a power market design based on nodal pricing, and discussed experiences that might address challenges emerging in Europe:

1. Can the interest of market participants in trading energy on short notice be balanced with TSOs' need for sufficient time to assess and adjust the dispatch to ensure system security?
2. For generation and load, the provision of reserve and response capabilities is linked to energy production and use, but energy is traded on separate platforms and at different times. Is integration necessary and possible?
3. The EU Target Model aims to facilitate joint trading of energy with transmission use – what lessons can be drawn from the US experience?
4. What are the merits of European transmission owners only trading energy to ensure system security versus US Independent System operators facilitating short-term market clearing?
5. How can the operation of the power system and energy markets provide information to support investment choices in grid and generation?

1. The Clash of Times: Flexibility vs. Addressing Constraints

Integrating increasing volumes of intermittent generation will lead to a conflict of time needs in power system operation. On the one side, market participants want increased flexibility to announce energy production changes on short notice, while TSOs need enough time to perform system analysis and re-adjust generation to solve network constraints.

- Since forecasting uncertainty decreases substantially in the final 24 hours before actual generation, wind production can be balanced more appropriately if all market participants have the flexibility to announce changes to output and consumption on short notice. European regulators have thus accommodated their requests by allowing generators to nominate output up to 30 – 60 minutes prior to real-time – called the gate closure.

- Conversely, in case any of these market-scheduled generation nominations are in violation of transmission constraints, TSOs need enough time to assess system conditions over the whole interconnected system (especially in meshed network of Central Europe) and ask generators to re-adjust their production accordingly.

Concerns and Implications:

Lack of contract firmness can jeopardise bilateral deals

Some TSOs include provisions in contracts with market participants that allow for the rejection of nominations of new generation/demand intraday schedules where these lead to constraints that are difficult to resolve. Since the other TSOs cannot plan for such changes, this complicates negotiations for bilateral (cross-border) energy trades, as it remains uncertain whether they can subsequently be executed.

Redispatch time conflict	In order to keep the system secure when faced with infeasible market results, system operators frequently need to initiate redispatch *prior* to gate closure (for instance, when thermal units need to be started up which can take several hours). Some regulators however request verifiable evidence of constraints that result from nominated flows *at* gate closure, before incurring redispatch costs; thus they ask TSOs to delay any actions.
Process presents opportunities for gaming	Market participants, who can observe redispatch actions undertaken by TSOs, might be encouraged to schedule additional transactions which contribute to the constraint(s) and subsequently benefit from participating in redispatch (the so-called increase-decrease 'inc-dec' game). Market monitoring could aim to identify such behaviour, but at times has failed (e.g. inc-dec game during California power crisis and on the UK gas network). Some TSOs sign ex-ante contracts with generators to reduce their short-term bargaining power or reduce gaming opportunities from recurrent and foreseeable congestions,
Challenges for international information exchange	TSOs exchange day-ahead information, allowing them to calculate expected flow patterns. This process currently requires some time to prepare relevant network models, and calculate and interpret the results. Unless effective congestion pricing limits market activities to feasible transactions, it is difficult for each TSO to interpret where and how these flows will be changed by TSOs to maintain system operation security.

2. Separate Markets for Energy, Reserve and Transmission

In Europe, operations of the power system and of the energy markets are clearly separated prior to gate-closure, with power system operation being handled by TSOs and energy traded bilaterally over-the-counter (OTC) and/or on Power Exchange(s).

Energy and Reserve Markets

- In most European countries, energy and reserves are contracted separately in energy markets and by TSOs (though some reserves are mandatory or remunerated on regulated basis). Generators however need to coordinate their provision of energy and reserves, and where they do not have a large generation portfolio might struggle to align the volume and time-slots when selling energy and reserves, resulting in inefficient production decisions. Integration of energy and reserve markets could allow generation and demand to adjust positions in both markets simultaneously, increasing flexibility for safe and economic system operation. The question was raised, whether TSOs could support Power Exchanges in facilitating an appropriate market place for both products, while ensuring complexities and system security are appropriately addressed.

- New demand-side technologies and control system require a transparent energy and reserve market that can adequately remunerate the value of all reserve products on the system and is seen to provide a long-term stable market interface that facilitates demand-side investment. Together with the design of the capacity markets, the transparent and integrated energy and reserve market in the PJM regional has resulted in 14 GW of demand contracted for reserve and response (corresponding to 7% of installed capacity). Thus demand flexibility has replaced fossil generation technologies as major source of system flexibility.

US Experience of Integrating Energy and Transmission Markets

- In some US markets, the flow-gate model was attempted. It was abandoned quickly because changing flow patterns increased the amount of interfaces that were critical, and could not be adequately integrated in the trading. Subsequently, a nodal pricing system was implemented in the respective liberalised markets.

- Location-specific information on generation, load and readjustments, in combination with the increasing regional coverage, improved PJM's understanding of current flow patterns and short-term forecasts. Over time, PJM (with an established Independent System Operator covering 13 states and District of Columbia in the US) was able to reduce operating margins to accommodate uncertainty. For example, the PJM 'Western' operational limit, set at approximately 20% of capacity 15 years ago, has been reduced to 1% of capacity today. On some European Interconnectors, transmission reliability margins, measured as the difference between total transfer capacity and net transfer capacity, are usually about 50%.

- In some jurisdictions, alternative options to nodal pricing were explored (e.g. use of flow gates), but ultimately failed due to inconsistencies between markets and operation.

3. Integrating Energy and Transmission: the EU Target Model?

The theoretical concept of the Target Model envisages a gradual evolution of current power market designs into a more integrated market, by improving and building on market coupling between countries. By 2015, it aims to implement a common framework that addresses system operation and energy markets concerns. To date, however, a set of design choices remain open and detailed quantification is needed to confirm that the concept is a viable option for the secure and economic operation of the European power system. These design questions are:

How to define bidding areas/zones?	Bidding areas can be defined as zones of any size (from node to multi-country). If zones are defined for more than one node, this raises the question of how to adjust zones if generation or load (and thus load flow) patterns change, or if new network topology increase constraints within zones (in Sweden, for instance, this required an EU competition commission inquiry)? How are difficulties for longer-term energy contracting avoided, if zones change over time?
How robust is the envisaged methodology for calculating transmission capacity between zones?	Transmission capacity between zones is envisaged to be calculated and allocated on a flow-based approach. This requires: (i) identifying critical network elements, (ii) deriving a DC approximation of the AC network for an assumed flow-pattern (iii) determining so-called *generation shift keys* (GSKs) to translate generation units to zones, that is, to calculate the power transfer distribution factors (PTDFs) for inter-zonal links.
(i) Definition of critical network elements	It is unclear which and how many critical network elements will have to be considered for system balancing. This choice will be the responsibility of each TSO who will have to justify their decision to the regulator. US experience with PJM suggests that the number can

"explode" with changing flow patterns. While the level of congestion within a set of US regions has historically been higher than within European countries, it is unclear how grid and generation investment patterns resulting from the Target Model approach will impact congestion in Europe.

(ii) Flow pattern for DC calculation

To calculate a DC approximation of the AC network, it is necessary to assume a flow-pattern. As the flow-pattern is difficult to forecast prior to market clearing, this raises the questions of how inaccurate the DC approximation will be, how to determine security margins to accommodate for this, and to what extent efficient network utilisation will be reduced. (In PJM, the ISO iterates between market clearing and AC-DC approximation so that the DC approximation is accurate for the flow-pattern).

(iii) Generation pattern for zonal approximation

The distribution of generation and load within a zone impacts the overall flow pattern, and is envisaged to be represented with GSKs. GSKs need to be calculated early so as to allow allocation of transmission capacity between zones, but are then still inaccurate because the precise generation patterns are unknown and can vary significantly from day-to-day. Again, this raises questions on how to determine the potential inaccuracy, derive security margins and assess implications for network utilisation.

How to facilitate intraday transactions?

With increasing shares of wind power, the location and type of generation adjusted intraday will increase to some extent (even if the day-ahead market will remain as a reference). The Target Model promises continuous intraday trade using a shared order book. However, with a flow-based approach to congestion management, any transaction will typically require access to a set of critical network elements and will compete with other transactions for these elements. This could thus be difficult to execute other than through a simultaneous optimisation across a set of transactions. Sufficient liquidity for such joint optimisation is likely to result only if adjustment bids and flexibility options are jointly presented at discontinuous auctions.

How to evaluate different power market design options?

A clear definition of the EU Target Model including the methodologies to quantify available transmission capacity is necessary for, and should be a reference for, the evaluation of alternative power market designs choices.

4. The US Experience with ISOs

The regulation of the European power system involves trade-offs between market and system perspectives. For example, shorter gate closure times shift intraday adjustments from the responsibility of the TSOs to bilateral and exchange based trading. However, as markets are not exposed to all network constraints, the TSO has to retain spare transmission capacity or contract flexible generation for redispatch in order to ensure system security.

In contrast, Independent System Operators (ISOs) emerged in liberalised US power markets as an intermediate institution that integrates both short-term market and system perspectives.

Why did US transmission companies agree to hand over responsibility to ISOs?	In the US, many transmission owners also own generation assets and therefore could therefore not host an unbiased market platform. They agreed to pass some operational responsibility to an ISO, because the money in the transmission business is in serving customers and investing in assets, not in system operation. On the contrary, system operation includes responsibility for power system failures. The ISO model allowed transmission owners to retain full control of their assets, pursue maintenance and run control centres that operate lines and switching gear without the risks associated with system operation.
Why did US marketplaces accept ISOs as a day-ahead and intraday trading platform?	As a regulated entity, the ISO has strict limitations on its operations which are primarily focused on day-ahead, intraday, and real-time market clearing. This provides the opportunity for private trading platforms and brokers to develop a variety of contracts to facilitate longer-term hedging based on transparent reference prices. To support these longer-term hedge contracts, the ISOs report prices for any aggregation of nodes as desired by the markets (hubs, zonal price, generation or demand volume weighted).
How large a system can be operated by one ISO?	Gradually expanding of the PJM control region increased the ISO's visibility of all system developments, enhancing system security and allowing more efficient system operation (current size 200 GW generation capacity). Ultimately it is the ability of operational staff at an ISO to maintain an overview across system developments that limits the size of the current model. To accommodate expansion, either an integrated ISO could internally develop separate, hierarchically structured, control centres or multiple ISOs can coordinate their activity.
How are neighbouring ISO regions coordinated?	As the control regions became increasingly interconnected, it was in the interest of the regional ISOs to develop closer operational links. For example PJM, NYISO and MISO swap, on an hourly basis, information on constraints and associated shadow prices on lines that are impacted by loop flows. These are then reflected in the intraday and real-time dispatch algorithm, so that they are jointly resolved at least cost.
Are ISOs necessary in Europe?	In European countries with successful vertical unbundling and regulation of TSOs, one could thus in principle also envisage that TSOs pursue system and short-term market operation activities that are executed by the ISO in the US.

5. A Landscape for Investment: Informed by Robust Data

An effective regulatory framework needs to facilitate efficient and secure system operation and, at the same time, provide appropriate incentives and support for network investment and locating generation and demand. What are the interactions between both objectives?

- The operation of the system and short-term markets can provide information on constraints – information that can inform some decisions on individual network expansions and identify the underlying drivers for expansion need. The shadow prices that emerge in congestion management that is based on the physical reality of the grid allow for some quantification of the value of such transmission expansion, and also provide the basis for simulations to model future network requirements.

- In principle, such shadow prices could emerge in flow-based and nodal pricing systems. However, it is not yet clear whether the flow-based approach envisaged in the European Target Model will use heuristics to set available transmission capacity or derive this based on a robust analytic approach. Only in the latter case will it allow for transparent evaluation of current grid expansion needs, and offer a clear framework for modelling network development plans and forecasting system adequacy.

- Transmission investment in US nodal pricing markets is partially informed by, but generally not financed with, congestion revenue. Even with nodal pricing, most investment remains within a regulatory process and are thus financed based on the regulatory asset base of the transmission owners (similar to the situation in Europe).

- The location of generation investment in US markets is partly informed by nodal prices. However, as nodal prices change with transmission investment, investors hedge against future changes of congestion and thus the value of generation at a specific location, with financial transmission rights (or equivalent auction revenue rights).

- Final retail customers across most US states with nodal pricing are not exposed to the nodal price. Instead, for a given system area, one zonal price is calculated based on the weighted average nodal prices within the zone. This weighted average price is then charged to all retail customers in the zone.

Outlook and Open Questions

The discussion on the European and international experience illustrates the close interactions between operational and commercial aspects of power system operation. Addressing these interactions in the energy market design enhances system security and allows for efficient utilisation of the existing assets, while increasing flexibility for large-scale integration of renewable generation.

While the discussion among TSOs has primarily focused on operational aspects, commercial aspects deserve equal attention. Integrating the discussions, e.g. using the example of financial transmission rights, could provide a suitable opportunity for another roundtable at a later date including both operational and commercial actors, and could address questions like:

- How would FTRs be designed in Europe?
- How would FTRs be allocated with increasing share of wind in the system?
- How will the structure of contracting for energy and reserves change with increasing shares of energy from renewable sources?