

# The impact of German HVDC lines on the European Electricity Market

Increasing transport requirements due to the continued increase in facilities remote from the load centre based on renewable energies and the new EU internal electricity market regulation are new challenges for the congestion management in the German transmission system. In order to contribute to the discussion on dealing with these challenges, the authors point to the strong interdependencies between HVDC lines within Germany, bidding zone configurations and nodal price indicators based on a scientific study.

The ambitious energy and climate policy targets, such as the “German federal government’s 65% target by 2030” [1] as well as the new EU internal electricity market regulation [2] to strengthen cross-border trade will lead to a significant increase in the power flows in the transmission system in the future. An increase in grid congestion situations is therefore expected. Besides long-term solutions involving increased grid expansion, additional preventive market-based alternatives, such as the adjustment of the existing electricity market design with new bidding zone configurations are being discussed.

To investigate the possible interactions between the discussed approaches, TenneT has worked together with the Institute of Power Systems and Power Economics (IAEW) at RWTH Aachen to analyse the systemic value of the planned German domestic HVDC corridors in a zonal electricity market design with different bidding zone configuration. This also identified the effects of these HVDC lines on the nodal price indicators and the bidding zone configuration derived as a result.

## Methods, input data and assumptions of the investigation

The analysis uses a fundamental electricity market and grid model to optimise the hourly generation and the associated costs. The investigations consider the year 2025 and take account of the ENTSO-E region based on the ENTSO-E Bidding Zone Review Study [3] pursuant to **Figure 1** (right). Within this area under review, a core region (shown in blue) was defined for the zonal and nodal investigations.

The electricity market simulation maps the flow-based market coupling within the core region and takes account of the new minimum requirements for the available transmission capacity on the market in accordance with the Clean Energy Package. The exchange with the remaining bidding zones in the area under review was modelled via bilateral NTCs. For the German domestic HVDC lines, it was assumed that they are already in use in the market coupling with the aim of maximising welfare.

To determine the redispatch volumes and costs in the zonal investigations, a grid operation simulation to eliminate congestion was then prepared for the core region to simulate the electricity market, which assumes an optimised cross-border redispatch. An integrated electricity market and grid operation simulation is used for the nodal investigations.<sup>1</sup>

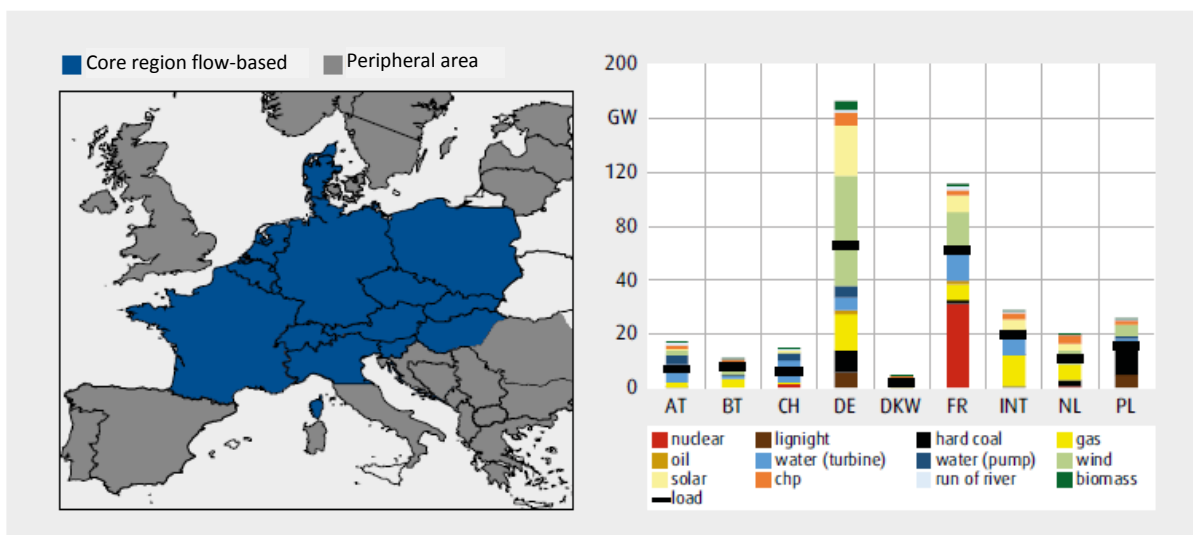


Figure 1. Area under review (left) and installed generation capacities in the countries (right)

<sup>1</sup> The node-based price indicators are calculated with the integrated electricity market and grid operation simulation. In this case, the price indicator reflects the fundamental costs of an additional unit of electrical energy on the relevant grid node at the relevant time in consideration of the (n-1) grid restrictions.

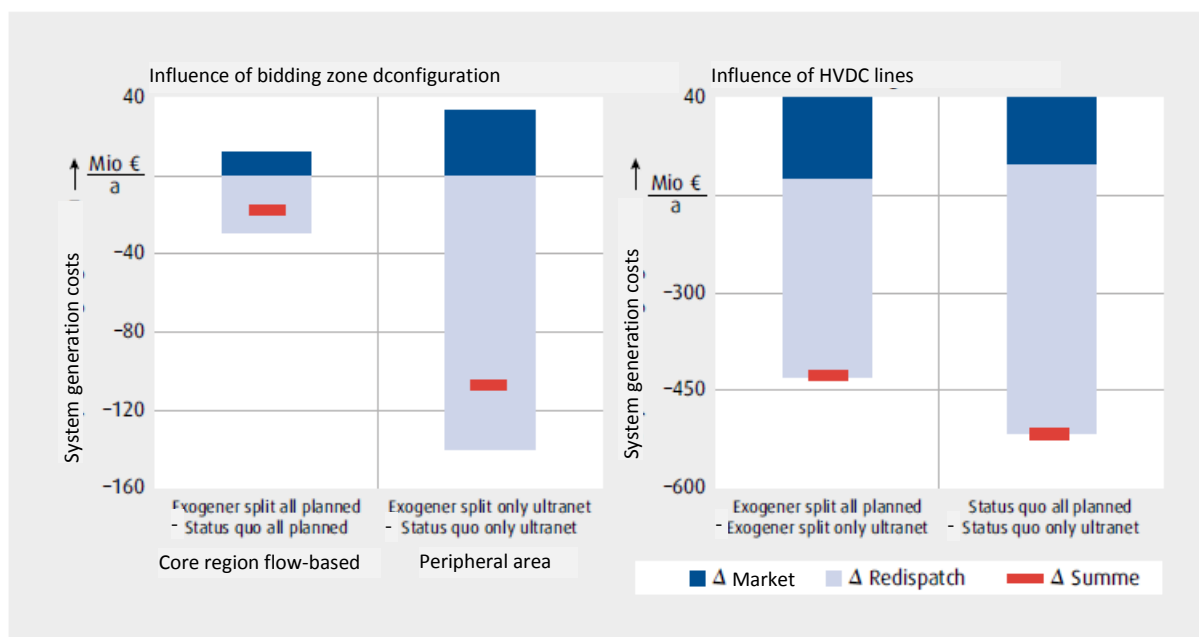


Figure 2. Change in system generation costs in the event of a different bidding zone configuration (left) and HVDC configuration (right)

The assumptions for the number of power stations and the grid status are based on currently published studies and analyses [4, 5].<sup>2</sup> The IAEW's European grid model used is based on publicly available data [6]. The confirmed measures from the 2017 GDP were taken into account for the German transmission system.

The zonal investigations consider two cases: Firstly, the status quo of a uniform bidding zone and, secondly, a splitting of the German bidding zone into two zones based on [3]. Besides determining node-based price indicators, the nodal investigation also summarises price-related grid nodes for bidding zones performed by a cluster algorithm.

For the zonal and nodal investigations, two HVDC configurations were compared to assess the HVDC lines:

- The *Only Ultranet* configuration exclusively assumes the entry into operation of the Ultranet HVDC corridor by 2025. The *All Planned* configuration assumes that all five planned HVDC lines are ready for operation in the year under review.
- The analysed scenarios are derived from the combination of the zone and HVDC configurations and were assessed by simulating the European market-side generation and grid-side redispatch costs (system generation costs). The cost differences between the individual scenarios can be interpreted as indicators of the fundamental value of a specific configuration.

<sup>2</sup> For the rest of Europe, the installed capacities of the conventional, hydraulic and renewable energy generation facilities pursuant to the Mid-term Adequacy Forecast [4] were parametrised. For Germany, the corresponding scenario as well as the cost assumption of the CO<sub>2</sub> certificates from [5] were used.

## The zonal market simulations

**Figure 2** presents the change to the systemic costs and the specific influence of the bidding zone configuration (left) and HVDC configuration (right). It clearly shows that the entry into operation of all German domestic HVDC corridors will significantly reduce the system generation costs in both bidding zone configurations. In the simulations, the fundamental costs decreased by between 430 and 530 million euros for the year 2025. The value of the HVDC lines during grid operations is particularly apparent and is distinguished by a considerable reduction in the redispatch requirements compared to the *Only Ultranet* scenario.

In the case of the *Only Ultranet* scenario, the exogenous split proves to be more beneficial for the system generation costs compared to a uniform bidding zone. While the generation costs on the market side increase as expected, due to the splitting of the bidding zones, they are overcompensated by the cost savings in the redispatch on the grid side. If all HVDC corridors are in operation, only minor cost differences can be identified between the considered bidding zone configuration.

Overall, due to an increase in the transmission capacity, the additional HVDCs always enable an indirect increase in the cross-border trading options on the market side while simultaneously significantly reducing the redispatch requirements on the grid side. In the split scenario, southern Germany and Austria in particular benefit from cheaper generation via the HVDCs as a result of the additional import options. The average price spread between northern and southern Germany could be significantly reduced with the additional HVDC corridors in the split scenario. In this case, it must be noted that the systemic cost benefits are merely an indicator for assessing the benefits of a modified bidding zone configuration and that a range of other criteria pursuant to the Regulation (EU) [7], such as transaction costs, are not considered in this article.

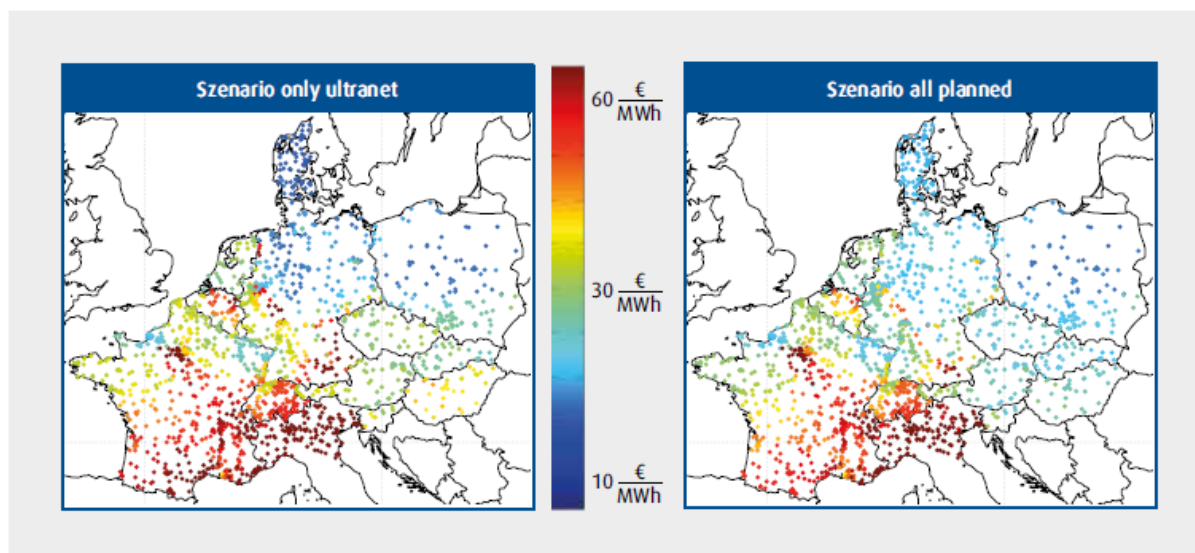


Figure 3. Annual average of the node-based price indicators

### Results of the nodal simulation

The average annual nodal price indicators in the core region for both HVDC configurations are shown in **figure 3**. In the *Only Ultranet* scenario, a clear price spread between the grid nodes in northern and southern Germany is apparent. While the average node prices are below 25 €/MWh in the north, high price indicators (above 50 €/MWh) are predominantly observed in the west and on nodes near the southern border. This results in a higher volatility of the nodal price indicators compared to the zonal unit price. Additional HVDC lines allow the determined north/south price spread in Germany to be reduced with a levelling of the nodal price indicators.

The new configuration of the bidding zones based on the calculated nodal price indicators depending on the HVDC lines are shown in **figure 4** (left for *Only Ultranet* and in the centre for *All Planned*). The price indicators are equally weighted in all hours independent of national borders, in which case the number of bidding zones corresponds to the status quo. Changes in the event of the bidding zone configurations as a result of the German domestic HVDC lines are particularly apparent in Central and Western Europe.

The bidding zone configuration determined in this manner is a possible solution, where the optimised configuration may differ considerably for a specific grid utilisation situation. This variability of the optimised bidding zone configurations at different points in time are clearly shown in **figure 4** (right) using the hour with the highest wind energy feed-in for the *All Planned* scenario by way of example.

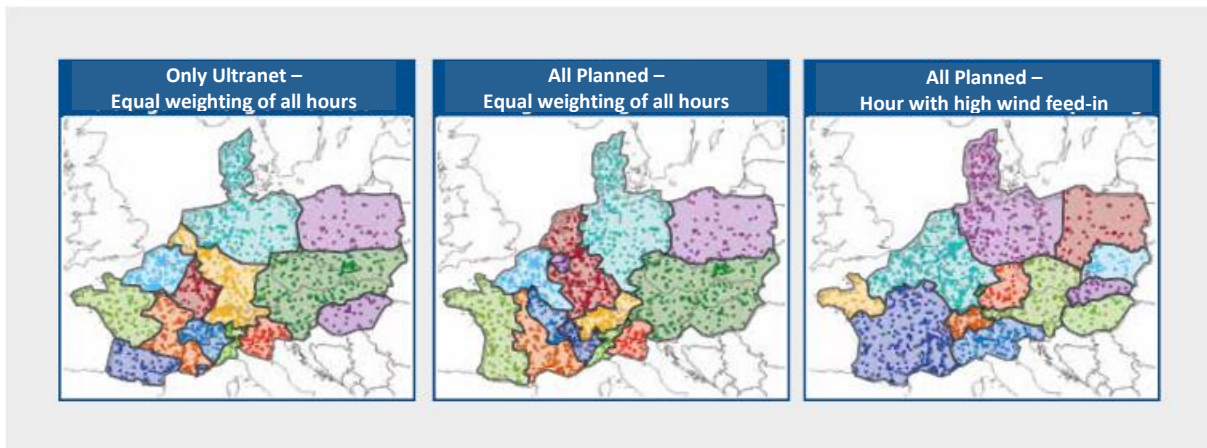


Figure 4. Bidding zone configuration in consideration of the hourly nodal price indicators

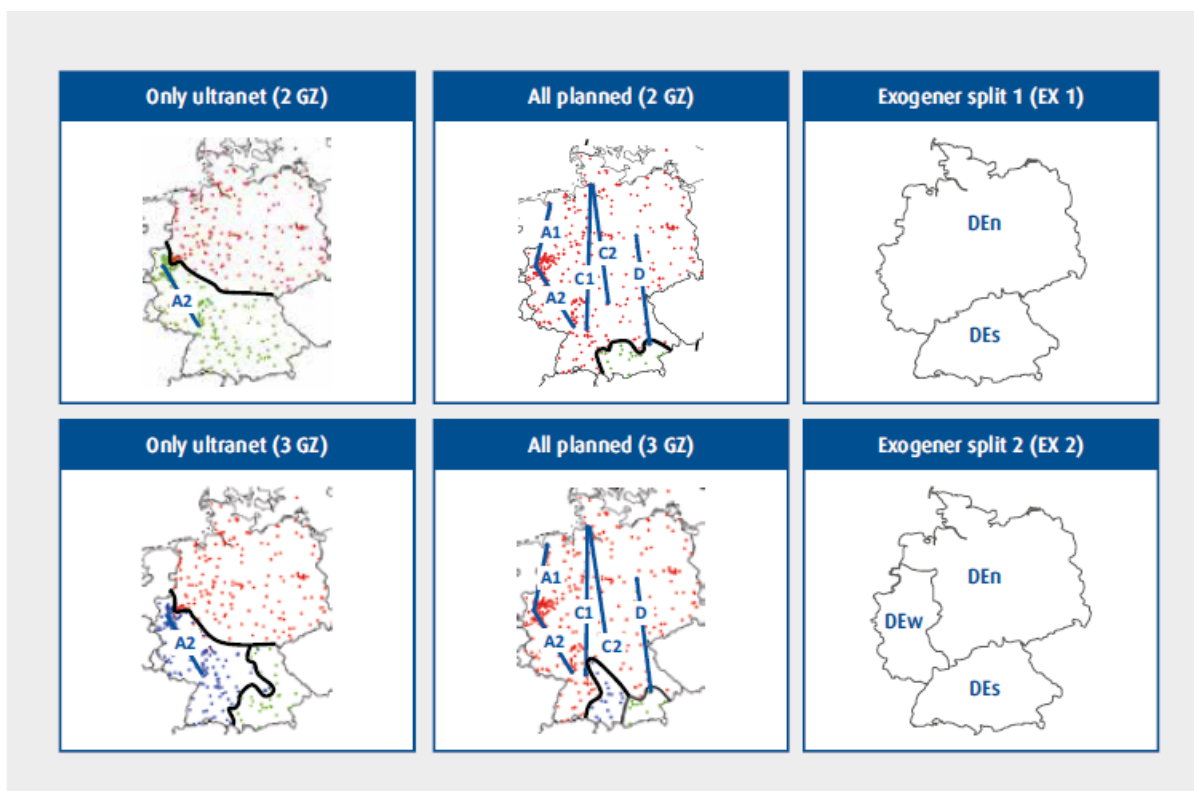


Figure 5. Bidding zone configuration for Germany based on nodal price indicators (left and middle) and the exogenous splits pursuant to the Bidding Zone Review (right)

In addition, the influences of the HVDC lines on the local bidding zone configuration in the event of the clustering of nodal price indicators were analysed for Germany by way of example, taking account of national borders and the exogenous specification of the number of bidding zones. The results are summarised in **figure 5** and compared with the exogenous splits from the Bidding Zone Review Study (right). For the specification of two as well as three bidding zones, the border between the new German bidding zones shifts much further to the south as a result of the additional HVDC lines.

The robustness of this bidding zone configuration depends on the following challenges:

- Optimal bidding zone configurations differ depending on the grid utilisation situation.
- Besides the grid expansion, grid utilisation situations are determined by a number of other parameters, especially the RE supply, the number of power stations and the primary energy prices.
- The determined configuration of the bidding zones depends on the cluster algorithm used as well as the measure for the similarity and weighting of situations.

## Conclusion of the study

The zonal investigations show the high systemic value of the grid expansion, in this case the German domestic HVDC lines, in the event of a bidding zone configuration in line with the last Bidding Zone Review Study as well as in the event that the current uniform bidding zone is retained. The results regarding the HVDC lines therefore prove to be robust in relation to the simulated German bidding zone split. The implementation of the planned grid expansion as well as the development of innovations for higher grid utilisation are therefore beneficial depending on the scenario and should be pursued as a matter of priority.

In the additional nodal investigations, it was also able to be shown that the model-based bidding zone configuration based on the nodal price indicators are significantly influenced by the additional HVDC lines. It must be noted that the splits for Germany endogenous to the model differ to the exogenous splits from the last Bidding Zone Review Study as a result of the modified framework conditions, such as the new EU internal electricity market regulation, among other things.

The discussions relating to future bidding zone configuration and changes to the electricity market design may acquire a new dynamic due to the modified framework conditions. The results of this study show the strong interdependencies between the grid expansion, the grid utilisation situation and possible bidding zone configurations.

The requirement for the robustness of bidding zones formulated in [7], together with the study results, leads to two considerations:

Firstly, in national and international grid planning processes, the positive contribution of measures for the maintenance or the robustness of bidding zone configuration should be investigated and included in the assessment.

Secondly, as the volatility in the grid utilisation increases, so do the challenges in defining robust bidding zones for a zonal market design, which points to a more frequent bidding zone configuration. Accordingly, fundamental changes to the market design, such as changes in favour of a nodal-based approach, should not be excluded from the discussion in the long-term, however the complexity of the associated advantages and disadvantages must be carefully considered.

## References

- [1] EU Commission: Clean Energy Package - Resolution on Regulation 2016/0379 (COD). Brussels, as of 2017.
- [2] German federal government: Climate Protection Programme 2030. Berlin, as of 2018.
- [3] ENTSO-E: First Edition of the Bidding Zone Review. Brussels, as of 2018.
- [4] ENTSO-E: Mid-term Adequacy Forecast 2016. Brussels, as of 2016.
- [5] The four German transmission system operators: Grid Development Plan 2019. Berlin, as of 2019.
- [6] ENTSO-E: Ten-year Network Development Plan. Brussels, as of 2018.



[7] Regulation (EU) 2015/1222 establishing a guideline on capacity allocation and congestion management

>> Dr.-Ing. **Denis vom Stein**,  
Institute of Power Systems and Power Economics (IAEW),  
RWTH Aachen

**Hao Chang** M.Sc.,  
Institute of Power Systems and Power Economics (IAEW),  
RWTH Aachen

Univ. Prof. Dr.-Ing. **Albert Moser**,  
Institute of Power Systems and Power Economics (IAEW),  
RWTH Aachen

Dipl-Ing. **Carsten Pflanz**,  
Team Manager Market Development,  
Tennet TSO GmbH, Bayreuth

**Benedikt Bartosch** M.Sc.,  
Advisor for Market Development,  
Tennet TSO GmbH, Bayreuth

Dr **Christoph Neumann**,  
Advisor for Market Development,  
Tennet TSO GmbH, Bayreuth

Dr **Friedrich Kunz**,  
Advisor for Market Development,  
Tennet TSO GmbH, Bayreuth

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[www.iaew.rwth-aachen.de](http://www.iaew.rwth-aachen.de)