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Definition of a Balancing Point for Electricity Transmission Contracts

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Definition of a Balancing Point for Electricity Transmission Contracts

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Luis Olmos and Karsten Neuhoff[1]

Electricity transmission contracts allocate scarce resources, allow hedging against locational price differences and provide information to guide investment. Liquidity is increased if all transmission contracts are defined relative to one balancing point, then a set of two contracts can replicate any point to point contract. We propose an algorithm and apply it to the European electricity network to identify a well connected balancing point that exhibits minimal relative cross-price responses and hence reduces market power exercised by generation companies. Market level data which is difficult to obtain or model such as price levels in different regions or that is dependent on the time scale of interaction, as demand elasticity, is not required. The only critical input quantity are assumptions on future transmission constraint patterns.

1 Introduction

Electricity transmission networks are frequently congested; market design addresses this issue either by defining physical transmission contracts which grant access rights to scarce resources or by integrating the allocation of transmission in the energy market under schemes like nodal pricing (Schweppe et. al. 1988), market splitting (Christie and Wangensteen 1998) or market coupling. These integrated design approaches allow for a more efficient use of the network in the

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presence of uncertainty and reduce the exercise of market power (Boucher and Smeers 2001, Neuhoff 2003). However, they need to be complemented with longer term (financial) transmission contracts for two reasons: first, they allow agents to sign long-term energy contracts if they are located at different parts of the network and would otherwise be exposed to uncertain locational energy price differences (Hogan 1992). Second, they provide information about future flow patterns to guide generation and transmission investment. In addition to this, transmission contracts enable grid promoters to hedge investment costs of a line by selling long-term transmission contracts in advance of the construction of the line.

Transmission contracts may pose, however, an obstacle to a competitive electricity market if they induce generation companies holding these contracts to exercise more market power (Cardell et.al. 1997, Borenstein et.al. 2000). In order to prevent this from happening, it is important that transmission contracts do not represent an extra incentive for agents to exercise their market power (Joskow and Tirole 2000). One approach discussed in Gilbert, Neuhoff and Newbery (2003) is to use specific allocation mechanisms, like a uniform price auction, to ensure that profit-maximizing generators only obtain transmission contracts that reduce their market power. However, with asymmetric information and uncertainty this approach does not seem to be sufficient and hence a restriction on holding transmission contracts might be required. One approach to further limit the potential exercise of market power is to choose one balancing point in the system towards which all transmission contracts are defined. Generation companies would be restricted to obtaining transmission contracts from the location of their generation facility to this balancing point and consumers would then obtain a transmission contract from the balancing point to their demand location.

Transmission contracts defined in this way have a number of advantages. Probably the most important one is the preventive effect that they may have on the exercise of market power. In addition, a lower number of transmission contracts are necessary. Instead of defining contracts between any two points, it is enough to define one contract per node in the system. This will increase the liquidity of transmission markets. Also related to this, these transmission contracts increase the number of trades among agents that do not have to be mediated through a centralized institution, which is required to redefine different contracts.

The impact of a balancing point for transmission contracts on the exercise of market power can be either positive or negative, however. The incentive for an agent located at any node to exercise market power will depend on the price change induced at the balancing point by a marginal increase in the output at this node. Transmission contracts defined using a balancing point could therefore change the exercise of market power in three different ways. First, the increase in the energy price at the balancing point may be smaller than that at the node where the agent decreasing its output is located. In this case, ownership of transmission contracts means that this agent will have sold in advance part of its energy at a more or less fixed price. Hence, it would have less incentive to exercise its market power than if it had not acquired these contracts.

Second, the increase in the price of energy may be the same at the agent's node and at the balancing point. Here transmission contracts will have no effect on the exercise of market power. Third and last, if the increase in the price of energy is larger at the balancing point, agents owning transmission contracts will have an incentive to withhold generation capacity. The value of their portfolio of transmission contracts would increase when they reduce output.

From this analysis, an important conclusion must be drawn. The price of energy at the balancing point should be as independent from the unilateral output decisions taken by agents as possible. Our search for a node that can be used as a balancing point has been driven mainly by the fact that this node must fulfill this criterion. The best-suited node according to this criterion would be unconnected to the network and hence exhibit no correlation with any price in the network. However, in this case a transmission contract would not only cover the risk of locational price differences, but also the usually higher risk of the overall price level. This would create two complications. First, the credit risk associated with such long-term contracts would increase drastically and hence complicated credit guarantees would be required which would preclude some agents from acquiring transmission contracts. Second, given the significant price-level risk covered by transmission contracts, agents would have to achieve a close match between their trade positions and the contracts they hold. This would eliminate the advantage of financial transmission contracts in environments of moderate transmission congestion expectations. Agents achieve sufficient hedging for locational price differences if the contracts cover approximately energy delivery, allowing the market aggregated contracts over a longer period of time, reducing transaction costs and increasing liquidity in the market.

Consequently, an additional criterion is required to capture the correlation of the energy price at the balancing point with energy prices in the remaining system.

In the US contracts can be signed for all locations while market designs like PJM allow market participants to obtain transmission contracts between any two locations to hedge for the corresponding locational price differences. Still, the attraction of trading at liquid markets reinforces the liquidity of the two main trading hubs. Thus, the exchange clearinghouse offers a monthly futures contract for electricity transactions based on the daily floating price at the PJM western trading hub. The PJM western hub consists of 111delivery points, primarily on the Pennsylvania Electric Co. and the Potomac Electric Co. utility transmission systems. Additional hedging opportunities are provided by means of options on this contract.(NYMEX, 2004).

We suggest retaining the liberty to trade at any location in the network, but propose to implement restrictions on transmission contract ownership. Such restrictions seem to be justified, because they complement an implicit restriction on the TSO in the transmission contract auction. The TSO is required to sell to any interested party transmission contracts as long as the net-contract volume results in a feasible flow pattern. Dominant generation companies can use mixed strategy bids in discriminatory auctions or possibly asymmetric information to obtain transmission contracts below the value these contracts are expected to obtain in the hands of these dominant traders. An arbitrageur would never issue such contracts, but the TSO would be required to do so. Hence the market design needs to correct for this constraint on the TSO behavior, e.g. by imposing a constraint on transmission contract ownership.

This more restrictive market design might be more important in Europe than in some of the US markets for two reasons. First, because the regional concentration of generation ownership is higher in Europe than in most of the liberalized US states. Secondly, because the regulators and competition authorities in Europe do not have the power of their US counterparts to intervene if the exercise of market power results in the deviation of prices from their competitive level.

2 Methodology and assumptions

Once we have determined the characteristics that the balancing point should have, we are in the position to decide which of the nodes of a large system such as the European one can qualify as balancing points. We computed relative cross-price responses for this system and a particular set of operating conditions corresponding to available data of the real operation of the system on January 17, 2001 at 10.30 am. The term cross-price response refers to the change in price at a certain node when the output at another node, hereafter referred to as the generation node, decreases by one unit. In order to compute the change in price at every node in the system we solve an economic dispatch based on the nodal pricing equations where some assumptions have been made that are explained in the following paragraphs. Relative cross price responses are the ratio between the change in price at any node and that at the generation node. Cross price responses are the solution of a linear equation system resulting from the traditional nodal pricing equations by algebraic manipulation.

We made the following assumptions in our model. First, active constraints remain binding once the power output at a certain node changes. Second, the net demand x_j at any node j=1...N in the system reacts to the price of energy according to a linear model:

$$x_j = D_j - \alpha_j p_j, \tag{1}$$

where D_j is the intercept, α_j is the net demand slope and p_j is the price of energy at this node. We assume that net demand slope α_j is proportional to the power generation at node j in accordance with the fact that most of the elasticity comes from the generation and not the demand side. We will show at the end of the section, that the proportionality factor does not affect the variables we will assess – relative cross price responses. As the appropriate proportionality factor would be difficult to determine and crucially depend on the time scale we are assessing, this independence facilitates the analysis. We are only interested in the marginal changes, hence the use of a linear demand function (1) in the algebra does not restrict the results from being equally valid for other functional forms. In fact, the actual output curves of generators are far from being linear. Most of them, though not all, either operate at their maximum capacity or do not produce any power. As we are assessing the impact of market power we should also anticipate that generation companies submit bid schedules that provide for less price responsiveness than the marginal cost curve of their generation assets would suggest. For example a Cournot bid does not provide any price responsiveness of output. Such behavior could be represented in our model by adjusting demand slope α_j with e.g. the regional HHI index of generation companies. It is part of future research to assess how such correction factors on α_j change the optimal balancing point.

Third, because the TSOs did not indicate which links were actually congested, we estimated the state of each line based on the ratio of the flow over the line to its capacity. Those lines with a flow to capacity ratio above 0.7 where assumed to be congested. The absolute capacity of a link does not affect the results, whereas we will discuss at the end of section 3.1 how the choice of constraints that are assumed to be binding can influence the results.

Finally, our computations include only one of those constraints that are highly collinear among themselves: We consider that each of these constraints represent the same limitation. Only after discarding highly collinear constraints were we able to solve the set of linear equations presented in (2), (3) and (4) in order to obtain cross-price responses.

We now calculate cross-price responses as resulting from traditional nodal pricing equations (Schweppe et. al. 1988) corresponding to an optimal power flow (Wood and Wollenberg 1984).[2] The global balance between load and generation in the system implies that the sum over all net-inflows equals the transmission losses, which we assume to be zero in our analysis:

$$\sum_j x_j = 0, \tag{2}$$

We assume that marginal output changes of a generator in the system with the resulting market reaction will not change the set of constrained lines C. Hence the net transmission on constrained links equals transmission capacity K_l. At the same time, net transmission equals the sum of all outflows x_j multiplied with the fraction γ_{jl} of the outflow that crosses link l on its way to the reference node. The

[2] An alternative market design of bilateral trading is described in Chao and Peck (1996).

reference node is the one that we have taken as the reference for computing energy prices. Hereafter, it is represented as r:

$$\sum_j -x_j \gamma_{jl} = K_l, \quad \forall l \in C \tag{3}$$

The market-clearing price at node j equals the price at the reference node r plus the marginal value of capacity between nodes j and r. The marginal value of capacity between nodes j and r is given by the sum over all constrained links of the Lagrange multiplier ρ_l associated with the restriction on the power flow for link l (equation (3)) scaled with the fraction γ_{jl} of the power flowing from the reference node r to node j across the link l:[3]

$$p_j = p_r + \sum_{l \in C} \gamma_{jl} \rho_l, \quad \forall j \tag{4}$$

Substituting (1) in equations (2), (3) and (4) and differentiating with respect to the intercept of the net demand D_i at generation node i, gives the following linear equation system for each generation node i that is considered:

$$\sum_j \alpha_j \frac{\partial p_r}{\partial D_i} + \sum_{j, l \in C} \alpha_j \gamma_{jl} \frac{\partial \rho_l}{\partial D_i} = 1, \tag{5}$$

$$\sum_j \alpha_j \gamma_{jl} \frac{\partial p_r}{\partial D_i} + \sum_{j, m \in C} \alpha_j \gamma_{jl} \gamma_{jm} \frac{\partial \rho_m}{\partial D_i} = \gamma_{il}, \qquad \forall l \in C \tag{6}$$

The equation system represented by (5) and (6) consists of C+1 linear equations with C+1 variables and thus can easily be solved by means of conventional algebraic matrix operations.

We first solve for $\frac{\partial \rho_l}{\partial D_i}$ and $\frac{\partial p_r}{\partial D_i}$ $\forall l \in C$, which allows us (4) to compute $\frac{\partial p_j}{\partial D_i} \forall j \in N$. These are the cross-price responses for every node in the system when the output at generation node i is marginally modified. Finally, relative cross-price responses are obtained by dividing price responses by that corresponding to the generation node i $\frac{\partial p_i}{\partial D_i}$. Assessing the relative cross-price response has the following nice feature:

[3] ρ_l corresponds to flow gate prices or shadow price of transmission constraints under nodal pricing.

Proposition 1: *The relative cross-price responses are independent of the assumptions about the relationship between power output and net-demand responsiveness.*

Proof: *Assume demand responsiveness to be scaled by X, then* α_i *is scaled by X and* D_i *change but does not appear in (5) and (6). Equations (5) and (6) will continue to be satisfied if* $\frac{\partial \rho_l}{\partial D_i}$ *and* $\frac{\partial p_1}{\partial D_i}$ *are scaled by 1 / X. Hence any sum of both, namely* $\frac{\partial p_i}{\partial D_i}$*, will also be scaled by 1 / X, and the ratio of two cross price responses scaled by the same factor 1 / X stays constant.*

3 Application of the method

3.1 The characteristics of the network

We study the synchronized European electricity network corresponding to the real system operation in 17 electrically connected UCTE countries on January 17, 2001 at 10.30 am. The UCTE model considered has 3,655 lines and 3,383 nodes of which 708 are generation nodes, a total level of production equal to 244.00 GW, a total load of 240.86 GW and losses of 3.14 GW (Pérez-Arriaga et. al. 2002). Figure 1 shows a map of the 17 countries comprising the system considered in the study.

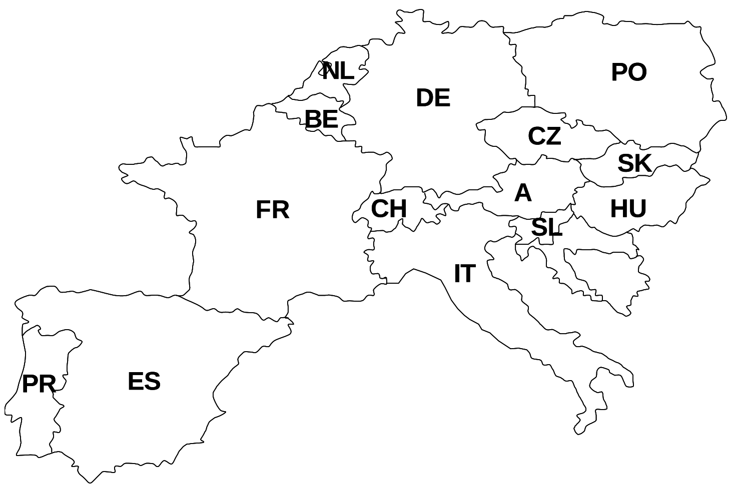


Figure 1: Geographical location of 17 UCTE countries considered in the study

Equations (5) and (6) provide the reaction of energy prices throughout the system to a change in the output at the chosen generation node *i*. The benefit of the marginal analysis is that we do not require any assumptions about the equilibrium price levels for the assessment of the relative cross price response.

Lets illustrate the impact of network constraints at the example of a generation node located in central Germany (KKPhili). Figure 2 shows the relative cross price response at various nodes of the European network as result of an output change at KKPhili. There were some nodes where the change in price was very significant whereas in others it was negligible. Due to the meshed nature of the grid, prices changed all over Europe and not only in the vicinity of the generation node. It is subject to future work to assess the sensitivity of relative cross-price responses to the set of binding transmission constraints. In an unconstrained world prices would only differ due to transmission losses and hence be highly correlated and relative cross-price responses would be around one. It is subject to further research to assess whether the typical European congestion patterns can be used to set boundaries on cross-price responses between different nodes and regions.

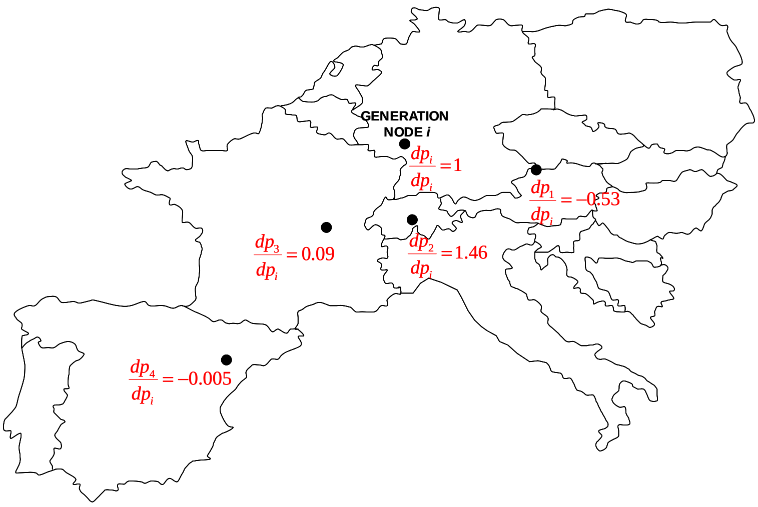


Figure 22: Impact on energy prices of a marginal decrease in the power output of an agent located in Germany (node *i*)

As could be expected, the price of energy at the generation node increased as a result of the decrease in the power output at that node. The absolute increase is a function of assumptions about demand elasticity and irrelevant in this analysis. Across the remaining nodes in the network, some turned out to have negative relative cross price responses. For example, if the power output at the German node KKPhil was reduced, the price at an Austrian node decreased. This effect might seem counterintuitive, but has been anticipated in the literature using analysis of simple networks.

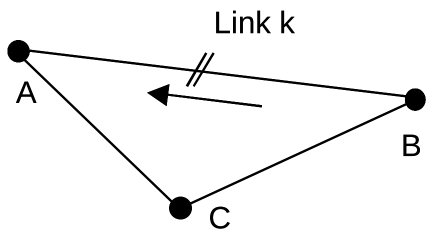


Figure 3: Example three node network creating negative cross-price responses

Assume in the three-node network of Figure 3 the transmission line between node A and B is congested towards node A. Then decreasing output at node A will increase price at node A and hence increase the scarcity value of the transmission line. Exporters from node B and C compete to use the transmission line. If the scarcity value of the transmission line increases, then exporters from C face a competitive advantage because their exports to A require a smaller fraction of the transmission line per unit of energy exported than exporters from B. Hence exports from B are reduced and price drops at B. Node B has a negative cross price response to output changes at node A.

We studied in detail the case of one of the many nodes with negative cross-price responses. Some constraint lines in the real scale system played the same role as that of line 'k' in the example of Figure 3. It cannot be claimed that this example explains why we obtained negative cross-price responses for some of the nodes in the system. It demonstrates, however, that this situation is perfectly possible.

3.2 Pre-selection of potential balancing points

As discussed in the introduction, it is not sufficient to identify a node that has low relative cross-price responses. We furthermore require that the balancing point should be well connected to the system as a whole. This ensures that the energy price at the balancing point is representative of the general evolution of energy prices in the system. Otherwise price changes of transmission contracts would represent not only locational differences but also an overall evolution of the price level. This would imply that the 'transmission' contract could take both large positive and large negative values. Hence, the counter-party risk that the holder of the contract would default in the case that the contract takes a large negative value increases significantly. This implies, that larger and more robust credit guarantees would be required, which increases costs and is likely to exclude some agents from acquiring transmission contracts.

Hence we need a criterion to judge how well connected a node is to the network. The own price response of a node represents the change in price at the node per unit decrease in the output at the same node. The larger a node and the better connected a node is to the network, the lower its own price response to output changes will be. If no constraints were binding every node would have the same own price response since all the system would respond to a change in the output at any node. This common price response in the absence of constraints is a suitable reference value to decide whether a node is well connected to the system. Only those nodes whose own price elasticity is below 10 times the unconstrained system's own price elasticity were considered well-connected nodes. Hence only these nodes are considered as potential balancing points in the analysis.

3.3 Node with optimal cross-price response

This chapter outlines the main results of our search for a suitable balancing node for the European system. Figure 4 shows the relative cross-price responses for each node of the UCTE system when output is changed at the node KKPhil in central Germany. The nodes have been sorted by their relative cross-price response.

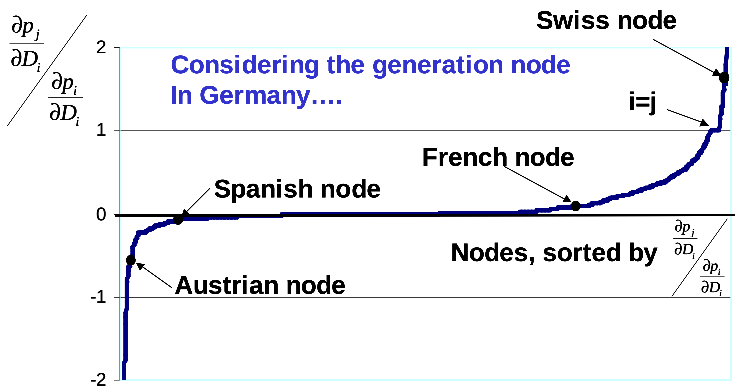
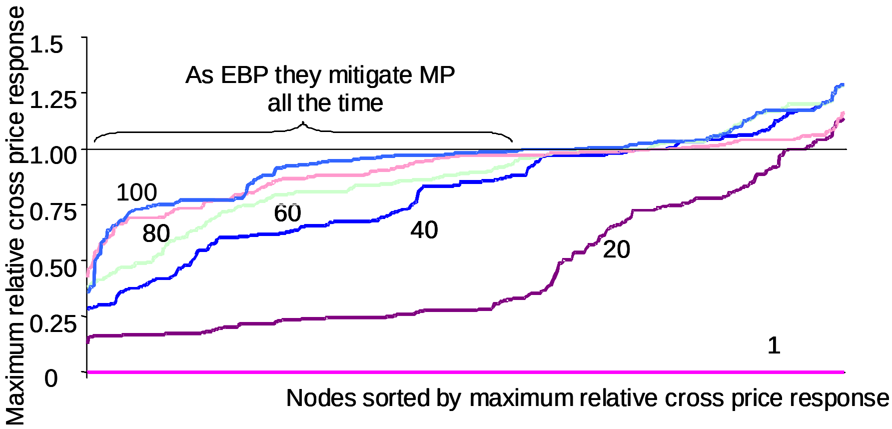


Figure 4: Relative cross price responses sorted by magnitude with the generation node located in KKPhili (Germany)

As discussed in the introduction agents with significant share in generation should be restricted to own contracts that hedge their transmission risk. No generator should be allowed to buy contracts corresponding to an import to its node. We now set up the additional requirement that relative cross price response of the balancing point with respect to the power injection at the generation node is below 1. This ensures that a generator reducing output will reduce the value of his transmission contract. This ensures that ownership of transmission contracts reduces the exercise of market power at the generation node.

The balancing point must mitigate the effects of market power at every node with generation assets. Hence it does not suffice to choose a balancing node that has low cross-price response relative to one German node, but we require that the balancing point exhibits low-cross price responses relative to all generation nodes of the network. Hence we should test for each potential balancing node, what are the relative cross-price responses it experiences to output changes at the remaining nodes of the network.

On the horizontal axis in Figure 5 potential balancing nodes are listed with the maximum relative cross-price response they exhibit if 20,40,60,80 and 100 generation nodes are considered.

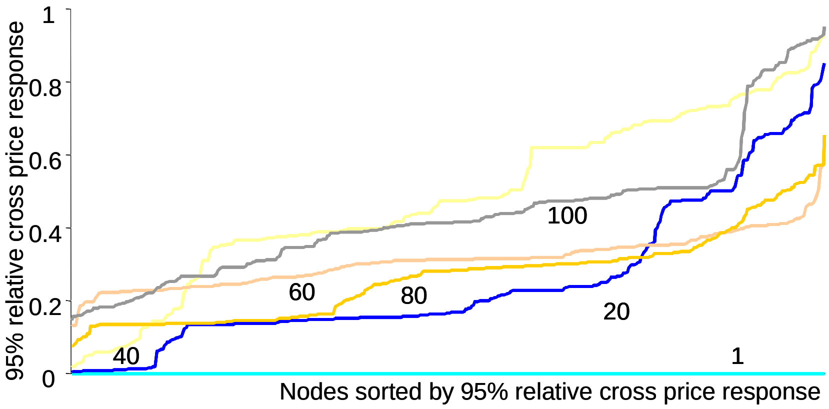


(Lines are labelled according to the number of generation nodes considered)

Figure5: Effect of the number of generation nodes considered on the shape of the curve representing the maximum relative cross price response for each node in the system

All the nodes with a maximum cross-price response below 1 mitigate the exercise of market power at any of the generation nodes considered. As the number of generation nodes under consideration increases from 20 to 100 the number of potential balancing nodes with relative cross price response of at least one increase. The more generation nodes we consider, the more probable it is that at least one generation node is very close to the balancing node and hence will have the same price and relative cross price response of one.

In order to exclude this effect, Figure 6 depicts the value of the relative cross-price elasticity of a node, such that 1/20 of the values we have obtained for this node are higher (95percentile). The graph illustrates that for growing numbers of generation nodes considered in the calculation, there is no longer a trend of increasing or decreasing values of the 95%-til of relative cross price responses. However, to ensure accurate results we use in the subsequent presentation the results obtained with all 708 that are defined as generation nodes in the snapshot.



(Lines are labelled according to the number of generation nodes considered)

Figure 6: Curves representing the 95th percentile of the probability distribution of relative cross-price responses for each node in the system. Each curve has been obtained for a different number of generation nodes

However, the approach of purely relying on the 95% creates the risk that nodes that may enhance market power could be regarded as being suitable as balancing points. Hence first nodes were selected that exhibited a maximum relative cross-price response below 1.1. In this group, nodes were ranked according to the 95 percentile of their distribution and the best 20 nodes were selected. Figure 7 illustrates the combined selection process.

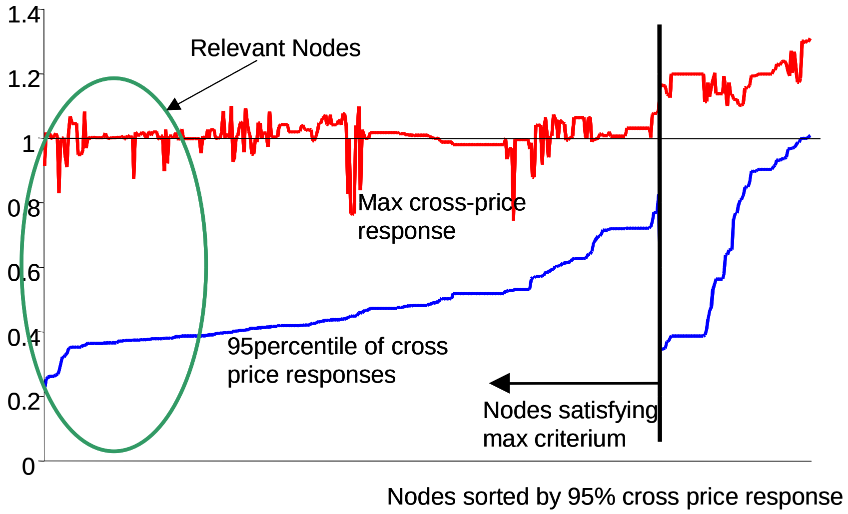


Figure 7: Election of the balancing point for the European system using both the maximum value of the distribution and the 95 percentile

The blue line represents the 95 percentile of the probability distribution for each node. It is divided into two separate segments. As explained in the graphic, the one on the left corresponds to the nodes whose maximum relative cross-price response is below 1.1 (and therefore those which can be thought to mitigate market power in any case). The curve on the right side corresponds to the rest of the nodes. The red line represents the maximum value of the distribution.

3.4 Discussion of results

Figure 8 illustrates the geographical distribution of the twenty nodes that are well connected, exhibit maximum relative cross price responses below 1.1 and show in this group the lowest 95% of relative cross-price responses. Based on this analysis the best candidate is the node labeled 'Langerak 132' in The Netherlands.

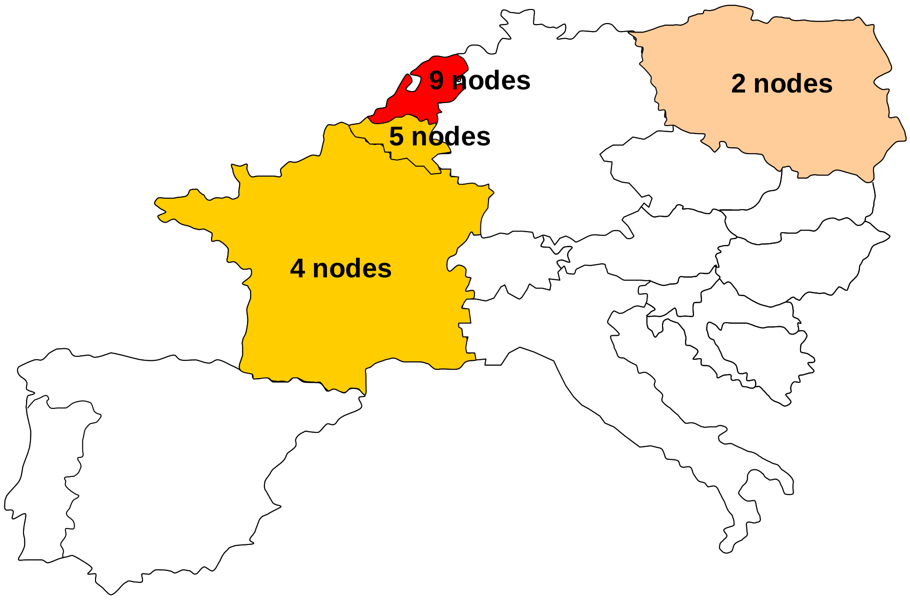


Figure 8: Geographical distribution of the 20 best candidates to become the European balancing point

It seems surprising that the algorithm identifies Belgium and the Netherlands as suitable balancing points, given that transmission constraints to these countries are well known thus implying that the criteria that nodes should be well connected to the remaining system is violated. This could imply that the criteria by which we selected well-connected nodes were not rigorous enough. In fact, if the threshold used to decide whether a node is well connected to the rest of the system were to be lowered to 5 times the reference value (instead of 10 times as before) the 20 nodes chosen as final candidates would be located in France. Additionally, the criteria we have used to locate congestions in the grid is unable to capture some of the constraints that TSOs take into account when operating their respective transmission systems. Both (n-1) type security criteria and the lack of efficient coordination in the management of the scarce capacity cause the importing capacity into the Netherlands to be reduced from more than 11000 MW to less than 4000 MW[4,5] (Institute of Power Systems and Power Economics, 2001). Some of the binding constraints affecting the area have been considered (some within Germany and on the border between Germany and France). However, others on the borders

[4] This would provide an additional argument for integrating different markets to ensure the network is used more efficiently while retaining the same level of system security.

[5] The day ahead prices for the 10-11am on 17th of January 2001 were 38.93 Euro/MWh at the LPX/EEX for Germany and 50 Euro/MWh at the APX in the Netherlands. This price difference indicates that available transmission capacity into the Netherlands should have been used.

between France and Belgium and between Germany and the Netherlands have not. Finally, more than one scenario is probably necessary to assess which are the relevant constraints. Changing regulations in most EU countries and the appearance of new trade opportunities between countries will probably significantly alter flow patterns in the European system. If the competing authorities decided to define transmission contracts towards a balancing point in the future, they should base their election on the possible flow patterns anticipated and not only the currently prevailing flow patterns. For example, the Dutch system operator, TenneT, states that it is possible that expected market evolutions may transform the Netherlands into a heavily transited country sometime in the future (Institute of Power Systems and Power Economics, 2001). Hence for an appropriate determination of the balancing point, the analysis should be repeated.

However, we have presented results that are interesting in that they show how closely prices are interlinked in the European network, and give an empirically based perspective on network interactions between regional electricity markets.

4 Conclusions

Both market power considerations and the possibility of simplifying the secondary trading of transmission contracts make it advisable to define transmission contracts between any point in the system and a common balancing point. If a generator decreases its output, the energy price at the balancing point should not increase by more than the price at the node where the generator is located, if it is to be ensured that the contract mitigates market power. Relative cross-price responses were computed using nodal pricing equations. Based on these responses, we have chosen a preliminary set of candidates to become the European Balancing Point. Despite being preliminary, the obtained results prove that the application of the methodology presented in the paper to a real large-scale system is feasible. One additional conclusion drawn from the results is that, contrary to what might be expected, output decisions by generators affect prices all around Europe and not only in the area surrounding the agent. This fact can be attributed to the meshed nature of the European grid.

However, conclusive results require further analysis. The effect that the selection of the set of binding constraints has on the results remains unexplored. The assumption that the net demand is proportional to the amount of generation available at each node should be reconsidered. More data on real demand levels would improve accuracy. Further analysis could also assess the impact that agents owning generation at different nodes may have. This circumstance may well affect the strategic decisions taken by agents.

Finally, the paper has only explored the possibility of using one unique balancing point for the whole system. Different balancing points can be defined depending on where each agent is trading its energy. A local balancing point for each national market may complement the European-wide balancing point to serve agents buying or selling energy locally.

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