Congestion Management in the Nordic Power Market

– Counter Purchases and Zonal Pricing

by

Mette Bjørndal[*]

Kurt Jørnsten[#]

Virginie Pignon[§]

Abstract

In this paper, we investigate methods for managing congestion on the grid in the Nordic power market. Specifically, we have considered the differences between using counter purchases as opposed to pricing out the transmission constraints of the grid. We show that the specific method used for congestion management greatly affects prices and therefore the surplus of the various agents, including the system operator. This means that the market agents may have preferences for one method, and take actions in order to influence which method is to be used. Based on this we have studied the incentives and possibilities of "moving" capacity constraints, and the effect this has on system performance. We have also looked into the differences between various pricing schemes, i.e. optimal nodal prices versus optimal zonal prices.

1. Introduction

In deregulated electricity markets, managing congestion on the grid is a central task for the system operators. Congested paths may indeed impede access to the market for generators, thus reducing the benefits due to the competition for electricity

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[*] Department of Finance and Management Science, Norwegian School of Economics and Business Administration, Helleveien 30, N-5045 Bergen, Norway, Tel: (+47) 55 95 92 90, Fax: (+47) 55 95 96 50, E-mail: mette.bjorndal@nhh.no.

[#] Department of Finance and Management Science, Norwegian School of Economics and Business Administration, Helleveien 30, N-5045 Bergen, Norway, Tel: (+47) 55 95 95 52, Fax: (+47) 55 95 96 50, E-mail: kurt.jornsten@nhh.no.

[§] Université Paris I, Centre ATOM, 106-112 Boulevard de l'Hôpital, 75634 Paris Cedex 13, France, Tel: (+33) 1 44 07 83 21, Fax: (+33) 1 44 07 83 20, E-mail: vir_pignon@yahoo.fr.

consumers, and creating potential market power for incumbent generators isolated from competition.

The Nordic power market, with one (non-mandatory day-ahead) spot market, run by NordPool, covers 5 control areas, i.e. Norway, Sweden, Finland and Denmark (split into two areas). Its creation implied the implementation of congestion management methods to alleviate congested paths. Congested paths may appear at the borders between zones, but also inside each zone. Without a mechanism to deal with the transmission constraints of the grid, the integration of the electric systems would just be a fallacy.

Nevertheless, the congestion management methods have not been standardized for the whole Nordic market, and differences remain according to the location of the congested paths. Two main methods are used:

- *zonal pricing* for the large and long-lasting constraints internally in Norway, but also for congestion at the borders between different control areas, and
- *counter purchases* for the internal constraints in Sweden, Denmark and Finland, and also to manage smaller internal congestions in real time in Norway.

The trading process for zonal pricing works approximately as follows:

1. Based on the supply and demand schedule bids given by the market participants to the spot market, the market is cleared while ignoring any grid limitations. It results in the system price for energy and the amount of electricity traded.
2. If these exchanges induce flows overloading transmission lines, the nodes of the grid are partitioned into different zones on either side of the bottlenecks.
3. A new pool price is determined in each area from the initial bids of the spot market, taking into account the maximum transfer capacity between the areas.

Thus, in accordance with the supply and demand curves, congestion is relieved through a market mechanism. This mechanism results in a revenue for the grid operator equal to the price difference between the areas times the amount of energy transmitted across the zone-boundary. The characteristics of the zonal pricing approach are studied in Bjørndal and Jørnsten (2001).

Counter purchasing is a completely different method as regards the trading process as well as the results for the market participants and the network operator. In short, it consists in constraining off some generators, rather ”ill-placed” on the grid as regards the congestion’s location, and constraining on ”better-placed” generators so that demand could be met.

The trading process to implement counter purchases works approximately as follows:

1. The first stage remains the same as with zonal pricing.
2. If these exchanges induce flows overloading transmission lines, the network operators check where injections into the grid have to be curtailed or increased, so that the congestion could be relieved.
3. These increases and decreases are implemented through separated markets (the ”balancing” market in Sweden and the ”regulation” market in Norway for instance). Agents offer adjustment bids on these markets, the sole buyer being the system operator.
4. The system operator selects the less expensive bids for increases and decreases. Thus, some generators may be constrained off and compensated with the equilibrium price of the market for generation reductions, whereas others are constrained on and receive the equilibrium price for generation increases.

This mechanism induces costs for the system operator since he has to buy and resell energy according to the adjustment bids. These costs are distributed among network users through the fixed charges of the network tariff.

Recently, consumers have been allowed to participate in the regulation market, and there is also a joint regulation list for the Nordic market. Moreover, the regulation market is applied both in order to secure momentary balance between supply and demand, and for congestion management (“special regulation”). For the latter it is possible to pick bids not only based on price, but also based on the effect the generation or load has on the specific congestion in question. These changes serve to improve the potential efficiency of the counter purchase method.

The aim of this paper is to highlight that the implementation of these two mechanisms may give an incentive to “cheat” on the rules. Thus, we illustrate by means of simple numerical examples that it is possible to “fake” a transmission constraint so that a real one could be managed. “Faking” a constraint on a given transmission line enables the use of one congestion management method rather than the other. Yet the relative benefits of “moving” a constraint are highly dependant on the pricing rule used as well as the network model used to compute the prices.

The rest of the paper is organized as follows. Section 2 provides an example of how it is possible to “move” a constraint from one transmission line to another. In the example we assume a full nodal pricing scheme. In section 3, we assume zonal pricing and see whether the results are affected by the pricing scheme. In section 4 we analyze an extended network to obtain more flexibility for the zonal prices. Thus, it is possible to check the effects of increasing the number of zones. Section 5 offers concluding remarks.

2. A Simple Example with Nodal Pricing

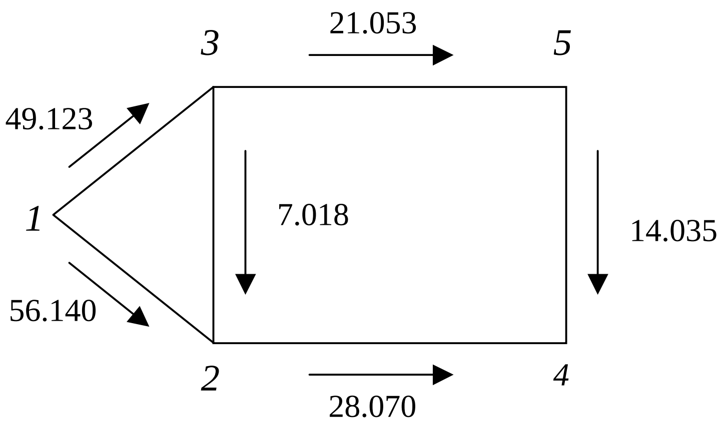
In the following example, we assume a linear and lossless ”DC” approximation of the power flow equations (Wu et al. (1996)), and we focus on real power. The flows of the network are determined by Kirchhoff’s laws, i.e. the junction rule and loop rule. The network considered contains 5 nodes connected by 6 electrically identical lines, like the grid of figure 1. In every node, there is both production and consumption, and we assume quadratic cost and benefit functions implying linear supply and demand curves. Demand in node i is given by $p_i = a_i – b_i q_i^d$, where p_i is the price in node i and a_i and b_i are positive constants. Supply is given by $p_i = c_i q_i^s$, where c_i is a positive constant. The parameters for the example are given in table 1. Demand is assumed to be identical in all 5 nodes, whereas supply is relatively cheap in node 1 and relatively expensive in nodes 2 and 4.

Table 1: Cost and Demand Parameters

Node	Consumption		Production
	a_i	b_i	c_i
1	20	0.05	0.1
2	20	0.05	0.6
3	20	0.05	0.4
4	20	0.05	0.8
5	20	0.05	0.3

Ignoring any grid limitations, the least cost dispatch of generation units entails the following electric flows:

Figure 1: Unconstrained Dispatch

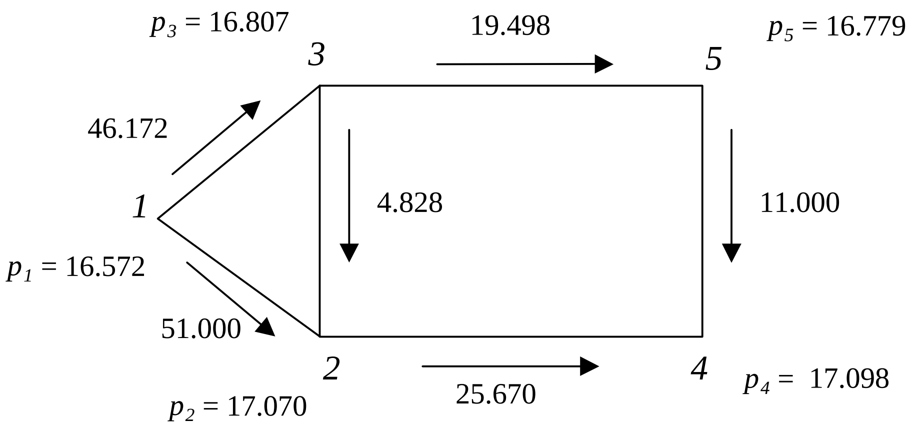


Since the dispatch is unconstrained, and we assume a lossless network, there is a unique price, the system price, which is equal to 16.842. The social surplus amounts to 3157. 895 and the grid revenue is zero since there is no congested path on the grid.

Considering the unconstrained dispatch, let us assume that the flows resulting from the spot market clearing entail two binding constraints: the first one on line (1,2), whose capacity limit is 51 units, and the second on line (4,5) with a limit of 11 units. The constrained dispatch, maximizing social surplus while reducing flows on lines (1,2) and (4,5) below their respective capacities, gives the optimal dispatch depicted in figure 2, where nodal prices and flows are displayed.

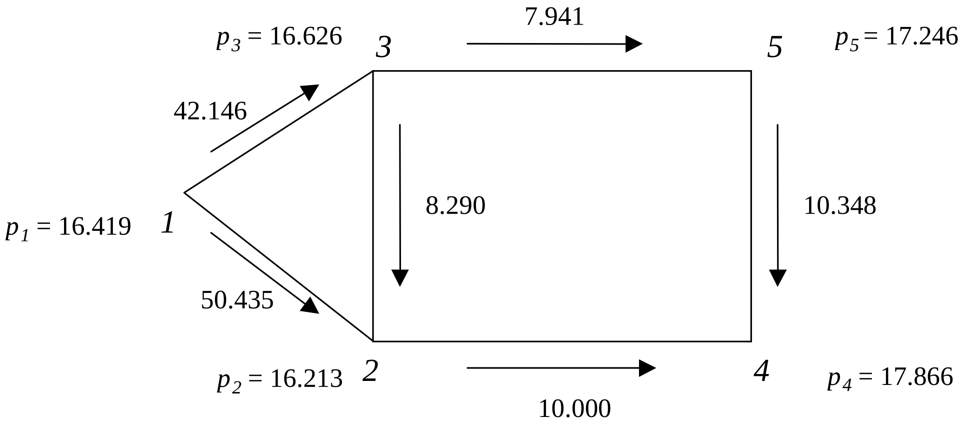
Due to the congestion, prices differ from one node to another. The variation in prices is about 3.17 %, i.e. rather small price differences across the network. As for the social surplus, not surprisingly, it is reduced to 3155.487 units. Indeed, the least cost dispatch had to be changed so that the congestion could be managed; hence the demand will be met by higher cost plants that, absent the constraint, would not run. Due to the congestion, these more expensive plants are constrained on. Nevertheless the social surplus is just slightly reduced, implying congestion costs of 2.408 units.

Figure 2: Constrained Dispatch: C_{12}=51, C_{45}=11



Let us consider now that rather than directly manage the internal constraints through a decrease in flows on lines (1,2) and (4,5), we put a "fake" constraint on line (2,4). For instance, we put a capacity limit of 10 units on this line. Once again, the prices computed are the optimal nodal prices, taking into account a capacity limit on line (2,4). The resulting flows are displayed on figure 3.

Figure 3: Constrained Dispatch, C_{24} = 10



In this case, the variation in prices is much higher, entailing larger relative costs and benefits for the generators and consumers located at each node. Here, the variation in prices across the grid amounts to almost 10.2 %. The social surplus now equals

3137.356 units, entailing congestion costs of 20.539 units, where congestion costs are measured by the difference in social surplus compared to the unconstrained dispatch. Nevertheless, the congestion on line (1,2) and (4,5) are both relieved when we “move” the capacity limits to line (2,4), and this “fake” constraint changes the price levels so that some network users could take advantage of this. However, if we take into account the congestion management mechanism, the incentives given by putting up a “fake” capacity limit may become much higher.

Indeed, we assume that this simple network represents in fact two markets linked with the cross-border lines (2,4) and (3,5). One of the markets, named market N is made up of nodes 1, 2 and 3, whereas the other one, market S, is made up of nodes 4 and 5. Consequently, the capacity limit of line (1,2) is now internal to market N, and the one on line (4,5) belongs to market S. This configuration can be seen as a stylized illustration of the Norwegian-Swedish grid. If the congestion management method used to relieve internal congested paths is different from the one used at the cross-border lines, then the incentives to “fake” a constraint on line (2,4) may be highly emphasized. The costs for the system operator resulting from counter-purchases would then disappear and be replaced by a possible income from grid revenues. In the above example, the costs from counter purchasing would at least be 2.408,[1] whereas the grid revenue when the capacity of line (2,4) is set to 10 units is equal to 22.732.

We have already noticed that the “fake” constraint entails a congestion cost, measured by the reduction in social surplus, much higher than when we manage congestion on line (4,5) and (1,2) by putting capacity limits directly on these lines. But the calculations made up to now are based on a nodal pricing scheme for electricity. It would be interesting to see how the results are affected when zonal rather than nodal prices are computed.

3. Implementing Zonal Pricing in the Example

Zonal pricing is an approximation of a full nodal pricing regime and results from the aggregation of nodes into zones, thereby reducing the number of different prices in

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[1] This assumes that the system operator can fully discriminate prices for increases and decreases and that the original bid curves are used.

the market. Stoft (1997) shows that the partition of the network into zones is generally not obvious, however, he states that it should be based on price differences. Yet, Bjørndal and Jørnsten (2001) show that a zone allocation mechanism based on optimal nodal price-differences does not necessarily lead to a zone system with maximal social surplus. In practical zonal implementations, the nodes at the endpoints of a congested line would typically be allocated to different zones.[2]

We consider again the simple example of figure 1/table 1. We assume that a boundary between the zones cut vertically lines (2,4) and (3,5), like in figure 4. Thus, the allocation of nodes into zones is fixed, which is more or less also the situation in the Nordic power market, as the national boundaries form fixed zonal interfaces, and Norway may be split into a few semi-fixed zones.[3] Let us consider first a simple example with only two zones, the first one consisting of market S (nodes 4 and 5) and the second one of market N (nodes 1, 2 and 3).

Obviously, the unconstrained dispatch will be the same as with nodal pricing, since we ignore any binding constraints. Yet, if we take into account now a "fake" constraint on one of the cross-border lines the results are completely different compared to the case of nodal pricing. Even with the same parameters, the way the prices are computed changes everything. Thus, as we did before, we put a capacity limit of 10 units on line (2,4) in order to decrease the flows on the real congested lines (1,2) and (4,5). The results are shown in figure 4. The flow on line (1,2) is reduced, but the flow on line (4,5) increases, thereby creating a potential conflict of interest between the system operators of the different zones as regards to the capacity announcements of the cross-border lines. The social surplus, equal to 3133.732 units, is reduced compared to the nodal pricing case with a constraint on line (2,4), implying that the aggregation of nodes into a limited number of zones increases the congestion costs, which amounts now to slightly more than 24 units.

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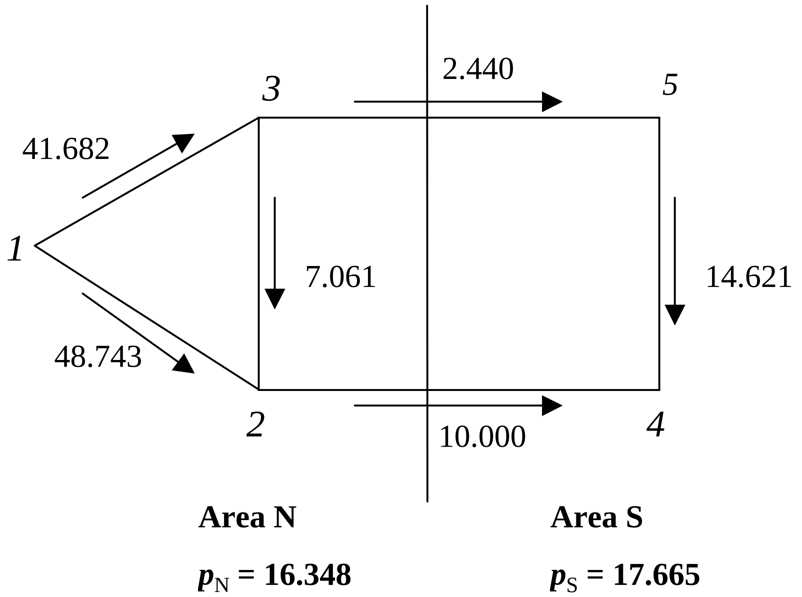
[2] Although this is not always optimal when we take into account more than one congested line (Bjørndal and Jørnsten (2001)).

[3] The zonal definitions within Norway are fixed beforehand, but can be redefined if there is special need for it.

Figure 4: Zonal Pricing with C_{24} = 10



If we put the capacity limit on line (3,5) rather than (2,4), the same potential conflict of interest appears with 14.540 units flowing on line (4,5) and 49.760 units on line (1,2). The social surplus is slightly higher and is equal to 3139.922. Thus, using a zonal approach to compute prices makes things completely different in our simple example. With only two price-areas, a “fake” constraint on a cross-border line is not enough to manage both the real internal constraints.

Therefore, let us consider that market N is in fact split into three areas so that each node represents one zone. Market S is still considered as a single area. We could expect that this further split in the market should give more similar results as in the case with nodal prices. In fact, the social surplus is just slightly increased compared to the two zones’ case (3134.970 units with a limit on line (2,4) and 3140.792 with a limit on line (3,5)), and even if only nodes 4 and 5 are aggregated now, the flows in the grid resulting from a “fake” constraint are quite different from the case where nodal prices were computed.

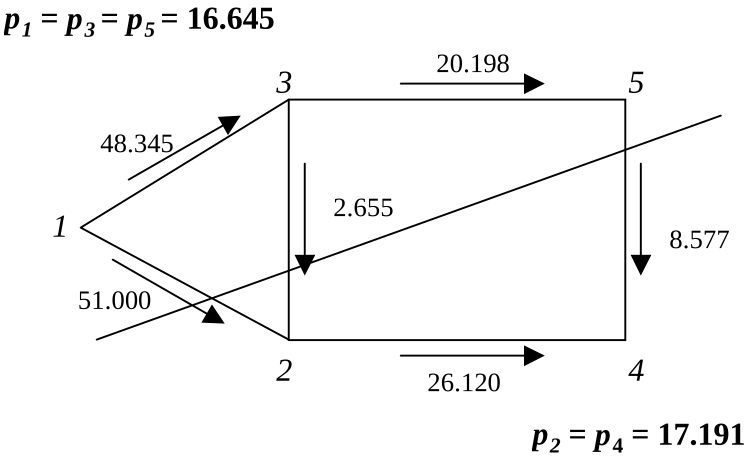
Table 2: flows on line (1,2) and (4,5) with a “fake” constraint on line (2,4) or (3,5)

	C_{24} = 10	C_{35} = 5
line (1,2)	50.472	48.936
line (4,5)	15.517	13.738

Once again, “faking” a constraint on the cross-border lines succeeds in reducing the flows on line (1,2) below the threshold of 51 units, but fails to manage the congestion on the internal congested line in market S.

Let us consider now that the zone-boundary could be moved, so that it cuts the congested lines. Lines (1,2) and (4,5) are consequently inter-zonal. Taking into account the real capacity limits of these lines for the dispatch of generation and loads gives interesting results, displayed in figure 5.

Figure 5: Alternative Zones with C_{12}=51 and C_{45}=11



Indeed, the social surplus amounts now to 3153.812 units. It is very close to the one resulting from the unconstrained dispatch, and thereby highly reducing the congestion costs to 4.083 units. Besides, the capacity limit of line (4,5) is not binding anymore. Thus, the management of the real congestion on the inter-zonal line (1,2) enables to alleviate the congestion on line (4,5). The allocation of the southern parts of markets N and S in the same area gives results that are very close to the optimal dispatch taking into account the capacity limits of the transmission lines.

These simple numerical examples point out that computing zonal prices makes things completely different, even if we consider competitive markets without gaming or related strategic behavior[4]. Zonal pricing is not a mere simplification consisting of reducing the number of different prices; zonal pricing does also change the allocation

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[4] For a study of market power with zonal pricing, see Harvey and Hogan (2000).

of social surplus among the market participants through averaged prices in each zone. Besides, fixing the boundaries between the price-areas, considering mainly the national borders irrespective of the electrical reality of the grid doesn't seem to be a consistent way to implementing zonal pricing. As we have seen in the last example, fixing the zones according to the location of the congested lines could give much more effective results.

On the other hand, the implementation of variable boundaries between zones may turn out to be quite complex. Thus Hogan (1999) computes the number of zones needed to implement zonal pricing in PJM. Even if the network is large and highly meshed, the results are worth taking into account. He uses actual data on nodal prices in April, May, June, July, August and September 1998. The criterion to select a zone is that the standard deviation of prices across the zone should be less than 10% of the average prices. It results in 94 zones in May, 75 in June, 57 in July, 52 in August and 64 zones in September needed to cover all the nodes. The zones are not the same in each month and sometimes, locations that should belong to one zone are not contiguous!

Implementing zonal pricing in a network with only 5 nodes though isn't really an easy case: there is indeed a lack of flexibility to aggregate nodes into zones with a uniform price. In the next section we will therefore consider a single constraint in an extended network. This will provide more flexibility in determining area-boundaries and area-prices.

4. An Extended Network

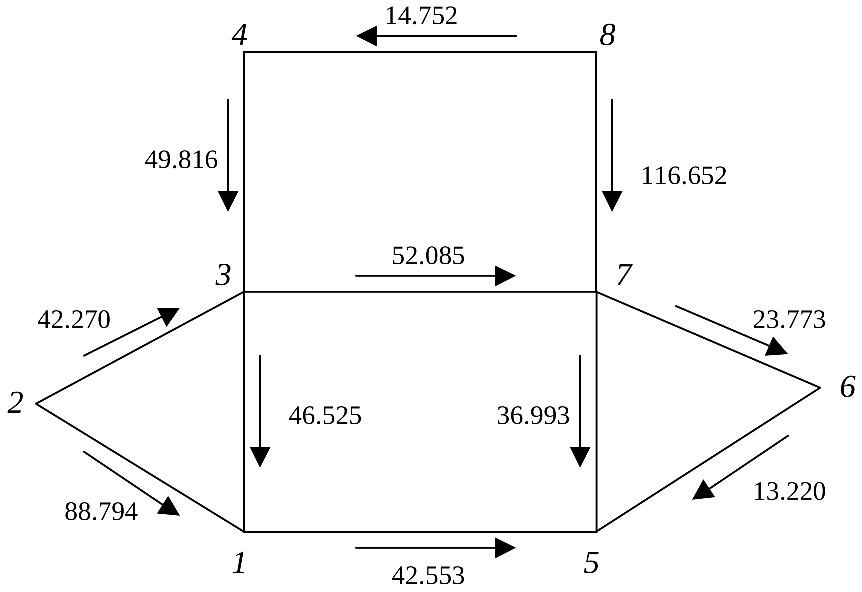
We consider a slightly larger network consisting of 8 nodes, 4 in market N and 4 in market S. The configuration of this example (see figure 6) is also inspired by the existing boundary between the Norwegian and the Swedish grids. We still assume that there is both production and consumption in every node, with quadratic cost and benefit functions implying linear supply and demand curves. Compared to the smaller example, we now assume different parameters for the cost *and* demand functions in each location. Implementing different b_i's could be interpreted as varying the sizes of the (nodal) markets. The chosen parameters given in table 3 seem well suited to the relative differences in the Norwegian and Swedish sub-markets.

Table 3: Cost and Demand Parameters

Node	Consumption		Production
	a_i	b_i	c_i
1	20	0.02	0.8
2	20	0.05	0.1
3	20	0.10	0.6
4	20	0.25	0.4
5	20	0.02	0.8
6	20	0.05	0.5
7	20	0.02	0.3
8	20	0.25	0.2

The unconstrained dispatch of the generation units needed to meet the demand is given by the following flows:

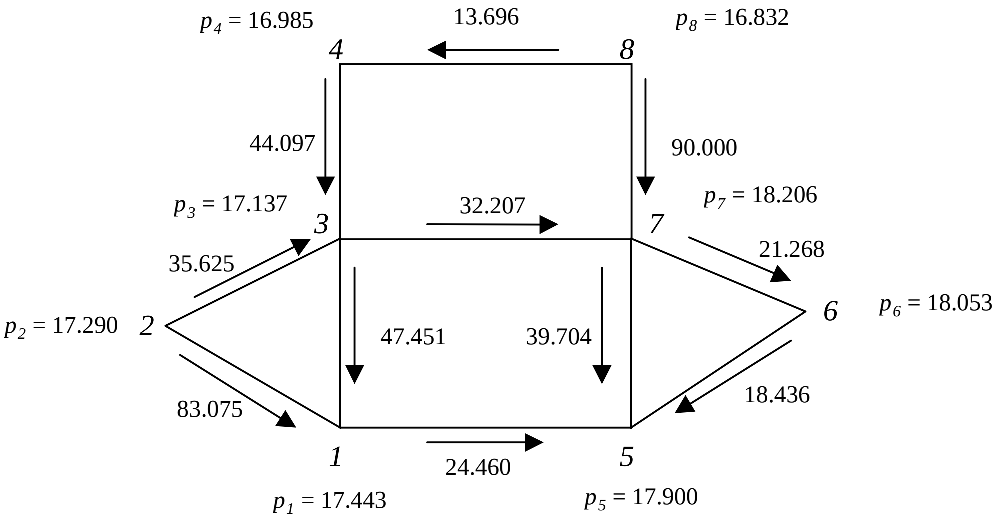
Figure 6: Unconstrained Dispatch



In this case, the social surplus amounts to 4779.574 units and the system price to 17.702. This non-congested situation reflects the market potential, however, we assume that this unconstrained dispatch of the generation plants violates the capacity limit on line (7,8), which amounts to 90 units. The management of the congestion will imply costs, thereby reducing the social surplus, as it was already the case with the smaller network, and again, the way this congestion is managed affects the final results for the involved parties.

We consider first the constrained optimal dispatch, where generation units and loads are re-dispatched so that the flow on line (7,8) does not exceed 90 units. Nodal prices and flows are displayed in figure 7.

Figure 7: Constrained Dispatch C_{78} = 90

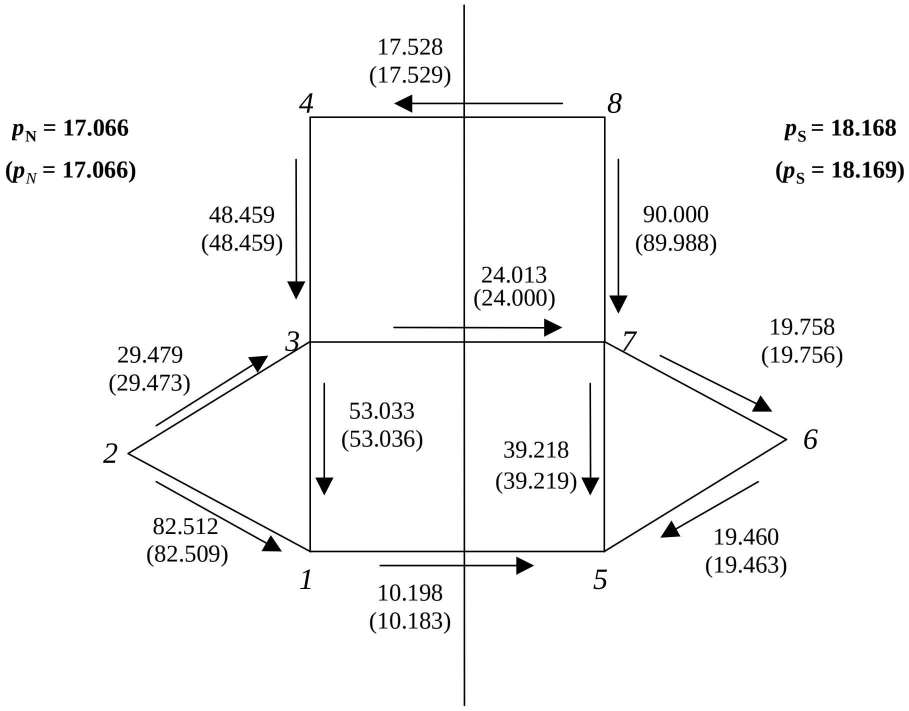


Now the social surplus amounts to 4759.236, entailing congestion costs of 20.338 units, and the single congestion on line (7,8) provokes different prices in each node. The optimal dispatch represents an upper bound on the social surplus that can be attained from any congestion management method. In principle, this solution could be obtained by nodal pricing or by a "perfect" counter purchase arrangement, taking into account the original bid curves of both suppliers and consumers in all nodes, and performing a least cost re-dispatch inducing a cost of 20.338 for the system operator. In this respect the nodal prices should be interpreted as nodal marginal values, and would apply only to the marginal quantities injected or withdrawn from the nodes.

Zonal pricing should simplify these nodal prices or nodal values through a reduction in the number of different prices. Besides, zonal prices, in the same way as nodal prices, should reflect congestion costs so that the energy flowing on line (7,8) does not exceed the capacity limit of this line. In this network, we first implement zonal pricing with two zones: zone N, consisting of nodes 1,2,3,4, and zone S, consisting of nodes 5,6,7,8. Thus there are now three cross-border lines linking the markets. The results, displayed on figure 8 are quite interesting. Here again the flows on the congested line amounts to 90 units, but the change in the way the prices are computed alters the flows on each line in the grid, thereby changing also the social surplus and the costs of the congestion. Indeed, these costs now amount to 34.795 units, which is an increase of 71% compared to the case with nodal prices. Thus, even without gaming, zonal pricing alters generation and consumption in each node, in a way that increases noticeably the congestion costs for market participants.

What is also interesting in this example is that if we take into account an incentive to "move" the congestion from the internal to one of the cross-border lines, it is possible to manage the internal congestion. Let us consider a "fake" constraint of 24 units on line (3,7). The resulting flows on each line are displayed in brackets in figure 8 while the results with the real constraint on line (7,8) are displayed without brackets.

Figure 8: Zonal Pricing (two zones)



Thus, “faking” a constraint on the cross-border line (3,7) relieves the internal congestion[5], and the zonal solution with the original constraint is replicated, giving the same flows as the real constraint and the same social surplus. However, since the constraint (7,8) is internal to price area S, it should have been resolved by counter purchases, and even if we assume competitive markets with adjustment bids equal to generation marginal costs, this mechanism entails costs for the network operator[6]. Resolving the constraint by zonal pricing on the other hand provides a grid revenue of 18.359 units, putting the limit of 24 units on line (3,7). Therefore, there is an incentive to “move” the internal congestion on line (7,8) to one of the cross-border lines, so that the management mechanism would be zonal pricing with market splitting, and not counter purchases. Hence, the real congestion is replaced by a replica, which is managed through a market mechanism, i.e. the change in supply and demand resulting from the zonal prices in each area.

Another way to cancel the costs of counter purchases would be to split market S into different zones, so that line (7,8) would become an inter-zonal transmission line. Hence, we assume now that zonal prices are computed with four zones, two in area N and two in area S, as depicted in figure 9. The boundaries cut lines (4,8), (3,7) (1,5) as before and, furthermore, line (3,4) in zone N and (7,8) in zone S. The results from moving the capacity limit to line (3,7) are displayed in brackets. Again we have assumed that the grid is operated as if there is a limit of 24 units on the flow of line (3,7).

When we consider four zones rather than two, the difference in flows and in prices between the case where line (7,8) is limited, and the case with a capacity limit on line (3,7) is substantial. A capacity limit on line (3,7) cannot replicate the solution for the real constraint on line (7,8). The results concerning the social surplus and the grid revenue are also different, as displayed in table 3.

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[5] In fact, this could also be achieved by putting a limit on the flow of line 1-5.

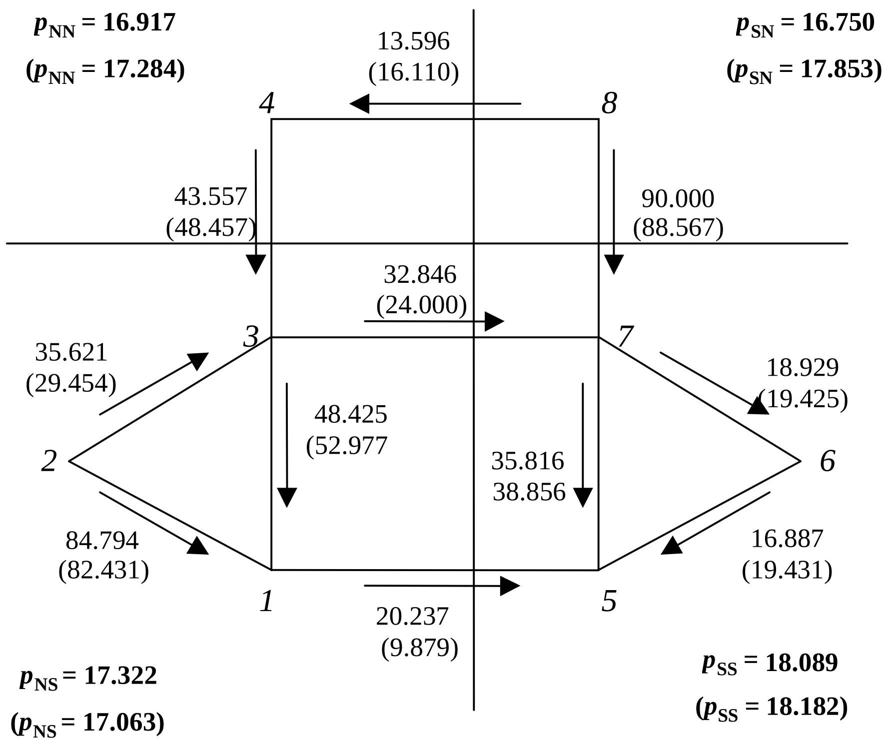
[6] For a study of gaming with a counter-purchase arrangement, see Stoft Steven [1998], “ Using Game Theory to Study Market Power in Simple Networks ”, Federal Energy Regulatory Commission.

Table 3: Social Surplus and Grid Revenue with Four Zones

	C_{78} = 90	C_{37} = 24
Total Social Surplus	4757.316	4745.334
Social Surplus Norway	2601.446	2613.535
Social Surplus Sweden	2018.723	2092.515
Grid revenue Norway	17.650	-10.720
Grid revenue Sweden	120.506	29.149
Grid revenue lines (1,5) (3,7) (4,8)	42.971	28.754

By using the actual constraint on (7,8) there is a considerable reduction in congestion cost when moving from 2 to 4 zones (from 34.795 to 22.258, i.e. very close to the optimal dispatch), but hardly any improvement when the network is operated with the constraint on line (3,7).

Figure 9: Zonal Pricing (four zones)



Once again, these figures point to the great interactions in an electric network, and the importance of operating a power system according to its real constraints. “Moving” a constraint, even with the same pricing rules and zones is not a neutral decision. This is very much illustrated by the differences that the agents experience as regards to the prices for the different solutions. The prices for the producers and consumers in node 8 for different solutions are given in table 4.

Table 4: Prices for Node 8 in Different Solutions

Pricing rule and Constraint	Price
Nodal pricing, $C_{78} = 90$	16.832
Nodal pricing, $C_{37} = 24$	17.836
2 zones	18.168
4 zones, $C_{78} = 90$	16.750
4 zones, $C_{37} = 24$	17.853

With four zones, the incentive to move the real constraint to line (3,7) vanish. Indeed the congestion on line (7,8) is managed through the price difference between the internal areas in zone S, thereby canceling the costs of counter purchases. Besides, keeping the real constraint brings about much higher grid revenues. Therefore, we could expect that “faking” a constraint would be much less interesting if the same mechanism was adopted to manage internal as well as cross-border congestion.

5. Conclusions

In this paper, we have illustrated the congestion management mechanisms used in the Nordic countries, i.e. zonal pricing on the one hand for the inter-zonal constraints, and counter-purchases for intra-zonal congested paths on the other hand. We have seen that the simultaneous use of these methods may give an incentive to “cheat” on the rules so that the congestion would be managed with one method rather than the other. It is indeed possible to replace a real intra-zonal congestion by a “fake” constraint on an inter-zonal line. The incentive is quite clear for the network operator that does not have to pay for the costs of counter purchases. The solution hence might be in a proper regulation that the network operator at least should enforce the same rules for intra-zonal and inter-zonal transmission lines. However, the incentive to move the congestion exists also for the market participants, that would face a decreased transmission tariff resulting from the lack of counter purchases' costs, and also (maybe above all) a change in the zonal prices resulting from the "fake" constraint. The incentives are all the more important as the boundaries between the zones are fixed since it is easier then to implement such strategic behavior.

We have also seen that zonal pricing makes things completely different, as regards the prices of course, but also as regards the flows on the grid, the congestion, the social surplus and the grid revenue. Hence, zonal pricing is not a mere simplification of nodal pricing; the aggregation of nodes into zones with uniform energy price does really change the allocation of social surplus among the agents, thereby bringing about winners and losers in the market with different and conflicting incentives. Therefore, the consequences of choosing zonal rather than nodal prices are extremely difficult to anticipate. Moreover, the differences in the optimal dispatch and different zonal solutions as regards to congestion cost for "real" and "fake" constraints indicate that there might be a reduction in social surplus from managing a constraint through a replica. However, in order to assess the exact cost for society, we need to take into account in detail how counter purchases are carried out, and how this secondary market functions. Modeling this market interaction is a topic for future research. Finally, as the prices vary considerably according to which constraint is considered in the solution, the prices that results from managing a "fake" constraint may be misleading as a signal of the usage of scarce transmission resources.

The subject investigated in this paper is related to the specific methods for relieving transmission constraints within the Nordic power market. However, the analysis and problems posed are of major concern when considering the integration of regional power markets with a meshed grid structure. Therefore, it should be of great interest for instance as regards to the creation of a European electricity market and the harmonization of various sub-markets within this.

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