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European Market Couplings: description, modelling and perspectives

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Abstract-- The “Trilateral Market Coupling” (TLC) between France, Belgium and the Netherlands was set up in November 2006. It allows an optimal allocation of the cross-border capacities that are submitted by the Transmission System Operators through an implicit auctioning mechanism. The level of price convergence in this region has given incentives to extend this mechanism to Luxemburg and Germany in the short term in the framework of the so called “Open Market Coupling”[1]. However, can the present process that rules the TLC be used for a five-market system?

This paper answers this question, relying on results obtained with two simulation models of the TLC and tackles the advantages and drawbacks of each model, in the perspective of their utilization for modeling the Open Market Coupling. Finally, advantages of a “flow-based” market coupling versus a “capacity-based” market coupling are discussed.

***Index Terms*-- Trilateral Market Coupling, Optimization, Flow-Based, Open Market Coupling**

I. INTRODUCTION

On November 21st 2006, an implicit auctioning process called “Trilateral Market Coupling (TLC)” was implemented between the Netherlands, Belgium and France to handle day-ahead cross-border capacity allocation. It complements the existing process of explicit auctioning to handle year-ahead and month ahead cross-border capacity allocation [2]. The TLC optimises the use of the day ahead (D-1) available cross-border transmission capacity, by a coupling between the three Power Exchanges (APX-NL[1], Belpex[2] and Powernext[3]) [3], and in cooperation with the relevant Transmission System Operators (TSOs), i.e TenneT, Elia and RTE. This mechanism allows the matching of energy transactions and the allocation of the relevant transport capacity. The Trilateral Market Coupling does not change the market architecture and rules, even if a certain degree of harmonisation is needed. In fact, while the three power exchanges are still legally separated power exchanges, the coupling is done thanks to a coordination module which does not need a common order book nor a common clearing. Besides, the Market Coupling mechanism is likely to be extended in order to integrate more markets.

The purpose of this document is to discuss the extension of the Market Coupling to Germany and Luxembourg in an “Open Market Coupling” on the Central West Europe (CWE), and in the long term its connection to Scandinavian countries. We adopted a model-based approach, in order to simulate the feasibility of the extension of the present TLC to a wider system. We built two models that simulate the behaviour of the TLC and then we compared the advantages and drawbacks of each model, particularly concerning the possible usage of each one in a perimeter of five countries.

II. MODELLING

In this part, we present first a modelling of the coupling of three interconnected markets that corresponds to a sequential algorithm and then an optimisation model.

A. *Sequential Model*

1) *Features*

This modelling corresponds to the “algorithmic translation” of the principles ruling the TLC [4], extended to three fully interconnected markets. This model has been built with the language Visual Basic for Application. Its inputs and outputs (available for the considered hour) are the following:

Inputs:

- Available Transfer Capacity (ATC) for each line and in each direction
- Net Exportation Curves[4] (NEC) for each market

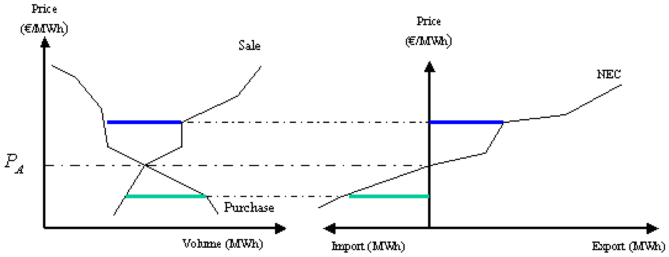

Fig. 1. From Bid and Offer curves to Net Export Curve

Outputs:

- Accepted bids/offers in each market
- Use of the Commercial Power Capacity on each line
- Market price for each market

The economic surplus, also called global welfare (W), can be computed by the model, supposing that we have the global supply and demand curves for each market and not only the NECs.

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[1] Dutch Power Exchange

[2] Belgian Power Exchange

[3] French Power Exchange

[4] Those curves are deduced by difference between the aggregated supply and demand curves (see Fig. 1). By definition, a NEC represents the price at which the market is willing to export.

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2) Operation

In a two-zone model, the lowest unused generation offer of the exporting area will be matched with the highest unused demand bid of the importing area, using the commercial capacity between these two areas. By this way, the price of the exporting area will increase, while the price of the importing area will decrease.

Then, either the ATC is not large enough to allow the whole exchange and a congestion occurs between the two zones, or the ATC is large enough and the prices of both markets become equal.

In our zonal model, the three considered markets M1, M2 and M3 – as presented in “Fig. 2,” – are sorted out by initial price[5], from the lowest (market A) to the highest price (market C).

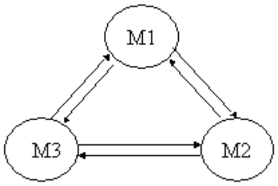

Fig. 2. Three-node system[6]

Then we distinguish two base cases:

- Base case 1: $|P_B - P_A| \le |P_C - P_B|$:

Markets A and B tend to export to market C.

- Base case 2: $|P_C - P_B| < |P_B - P_A|$:

Markets B and C tend to import from market A.

The two markets with the closest prices will be treated together. In the base case 1, markets A and B represent the – *a priori* – exporting area, and market C represents the importing area. In case 2, market A is the exporting area, and markets B and C represent the importing area.

Therefore, we choose to handle the NEC separately, using a loop that selects the cheapest offer of both NECs in the first case, or the highest offer in the second case.

As a result, we can model the three-market situation using a two-market model which couples the two markets whose prices are the closest.

In the base case number 1, markets A and B export towards market C, so the model will skim through the NECs of A and B (at each price, in increasing order, it considers the offers from both markets), accepting the less expensive offer, until a congestion appears or until the price of the market A or B reaches the price of the market C. Each accepted MW leads to a translation of the NECs of both importing and exporting countries, and a calculation of the new marginal prices of the relevant markets. It also decrements the remaining amount of available power on the concerned transmission interface. For example, if the offer proceeds from market A (respectively from market B), the transmission $Q_{A\rightarrow C}$[7] (resp. $Q_{B\rightarrow C}$) is decremented as a priority. When this value reaches zero, there is no more remaining capacity on this interface, and the model uses the alternative path and then decrements both transmissions $Q_{A\rightarrow B}$ and $Q_{B\rightarrow C}$ (resp. $Q_{B\rightarrow A}$ and $Q_{A\rightarrow C}$).

When any of this value reaches zero, the loop is over and market A (resp. B) gets isolated. Then, the model tries to couple markets B and C (resp. A and C), provided there is enough capacity on the interface between B and C (resp. A and C). If this is not the case, the three markets get separated, with three different prices.

This is quite symmetrical in base case number 2.

All the possible cases and different configurations of the system are implemented in this sequential algorithm. Since the more countries the more cases to handle, this modelling does not seem to be a fair one for four or more countries. Moreover, with four interconnected markets, there can be up to six interfaces, and thus multiple paths for commercial exchanges between two markets. Finally, the – *a priori* – exporting zone and the – *a priori* – importing zone are much more difficult to identify.

B. The ATC based optimisation model

At the same time, another model has been developed, relying on a system-wide optimisation [5]. This modelling corresponds to the “mathematic translation” of the principles ruling the operation of the market coupling which is maximising the social welfare of the actors, under the constraints of respecting the allowed transfer capacities (i.e. the ATC). This model was built using GAMS software.

The inputs of the model are :

$P_{S(j,n)}$ and $Q_{S(j,n)}$: Price and volume of the offer j on market n
$P_{D(i,n)}$ and $Q_{D(i,n)}$: Price and volume of the bid i on market n
$ATC_{(n,m)}$: Available Transfer Capacity from market n to m

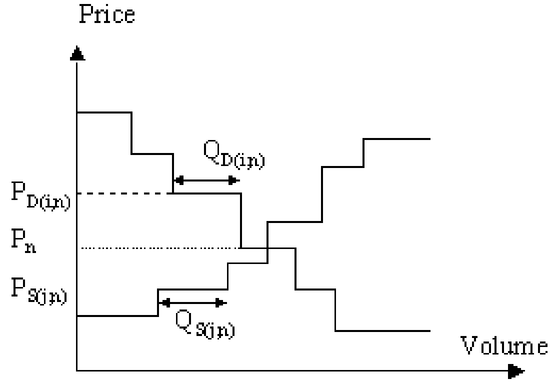

Fig. 3. Parameters of the optimization model

The variables are :

$X_{S(j,n)}$: Accepted volume of the offer j on market n
$X_{D(i,n)}$: Accepted volume of the bid i on market n
$Exch_{(n,m)}$: Commercial exchange from market n to m

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[5] The initial price of a market corresponds to the price of the isolated market (the price of the internal energy transactionsif there is no interconnection at all). It is given by the intersection of the NEC curve and the Y-axis.

[6] In reality, France, Belgium and the Netherlands are interconnected without direct link between France and the Netherlands, nevertheless our model deals with the general configuration.

[7] Initially, this value equals to the ATC between the corresponding markets.

Considering N interconnected markets, the objective function to maximise is the following:

$$F=\sum_{n=1}^{N}\left(\sum_{i=1}^{I_n}P_{D(i,n)}\cdot X_{D(i,n)}-\sum_{j=1}^{J_n}P_{S(j,n)}\cdot X_{S(j,n)}\right) \qquad (1)$$

The left member of (1) stands for the willingness to pay of the buyers, and the right one corresponds to generation merit order multiplied by the corresponding accepted volume.

The constraints to take into account are the following ones:

Equilibrium condition on each market:

$$\sum_{j=1}^{J_n}X_{S(j,n)}-\sum_{i=1}^{I_n}X_{D(i,n)}+\sum_{m\neq n}\left(Exch_{(n,m)}-Exch_{(m,n)}\right)=0 \qquad (2)$$

Global equilibrium condition:

$$\sum_{n=1}^{N}\left(\sum_{j=1}^{J_n}X_{S(j,n)}-\sum_{i=1}^{I_n}X_{D(i,n)}\right)=0 \qquad (3)$$

Respect of the Available Transfer Capacities:

$$\begin{cases}\forall n,m\\ 0\le Exch_{(n,m)}\le ATC_{(n,m)}\\ 0\le Exch_{(m,n)}\le ATC_{(m,n)}\end{cases} \qquad (4)$$

Respect of the Available Volumes for Bids and Offers:

$$\begin{cases}\forall i,j\\ 0\le X_{S(j,n)}\le Q_{S(j,n)}\\ 0\le X_{D(i,n)}\le Q_{D(i,n)}\end{cases} \qquad (5)$$

III. SIMULATION AND RESULTS

We focused on six situations, based on the same framework of theoretical data, in order to compare the results of simulations launched with both models. The system consists of three interconnected markets, as illustrated on "Fig. 2,".

The supply and demand curves of each isolated market are given on "Fig. 4," to "Fig. 6," and are the same for the six situations. Each situation relies on a set of values of the transmission capacities between market zones. ATC are supposed to be equal in both directions.

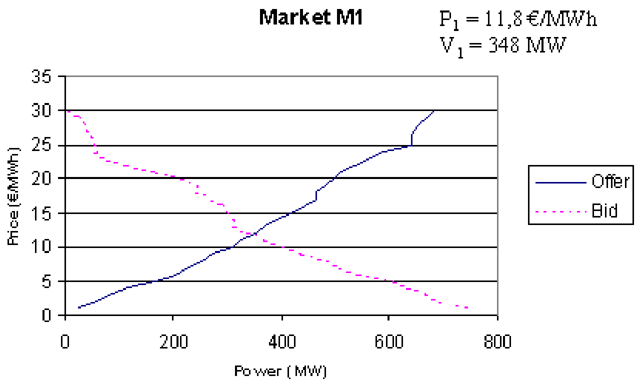

Fig. 4. Bid and Offer curves on Market M1

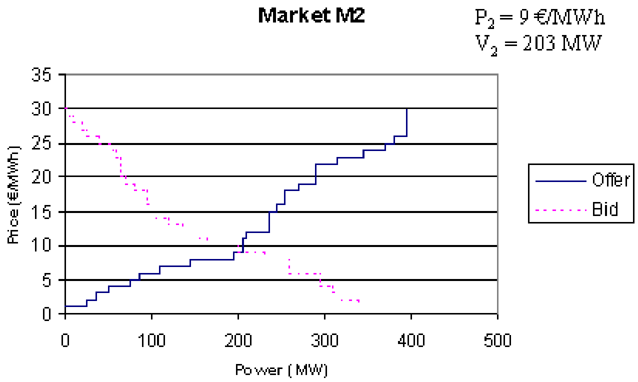

Fig. 5. Bid and Offer curves on Market M2

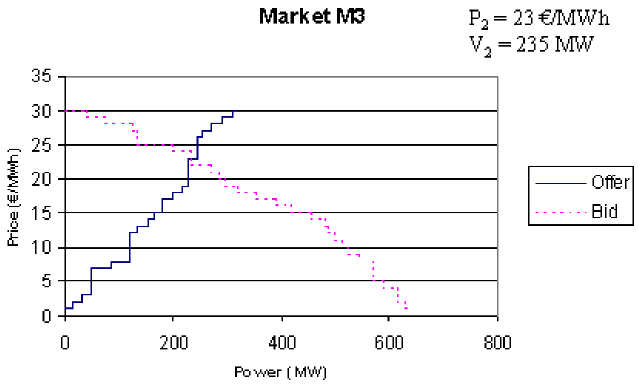

Fig. 6. Bid and Offer curves on Market M3

The value sets of ATC for each situations where chosen to simulate several situations that may occur in reality. They are reminded in the Table 1 as well as the final social welfare value (W) and the final values of the price in each zone (P_i), using both models.

The situation (o) corresponds to a situation with no interconnection lines between markets. Obviously, both models give the same result as there is no capacity to allocate. The three markets are isolated with three different prices and the value of the social welfare (11600€) is the minimum that can be reached with the considered bids and offers as described in "Fig. 4," to "Fig. 6,".

The situations (i') corresponds to a "copper-plate" with three interconnected markets. There is a full price convergence.

In situations (i) to (iv), the ATC between markets 1 and 3 where set to zero. This is a way to simulate a case of three interconnected markets that are aligned. It corresponds to the actual situation involving France, Belgium and the Netherlands.

As expected, in the situation (i), interconnection capacities are large enough to obtain the same results as for the situation (i'). In this case there is a real coupling for the three markets and the value of the social welfare (13100€) is the maximum that can be reached with the considered bids and offers as described in "Fig. 4," to "Fig. 6,".Compared to the case of isolated markets from situation (o), the surplus has increased by 13%, thanks to the coupling.

In situations (ii) and (iii), the coupling only involves two markets whereas in situation (iv) the three markets are splitted as in situation (o) but prices are closer and the social welfare (12400€) is higher than in situation (o) as cross-border transactions have been concluded.

TABLE I
SIMULATION RESULTS FOR THE SIX STUDIED SITUATIONS

	ATC			Sequential model				Optimisation Model			
	1→2	1→3	2→3	P_1	P_2	P_3	W	P_1	P_2	P_3	W
(o)	0	0	0	11,8	9	23	11600	11,8	9	23	11600
(i')	1000	1000	1000	15	15	15	13100	15	15	15	13100
(i)	1000	0	1000	15	15	15	13100	15	15	15	13100
(ii)	1000	0	80	12	12	19	11900	12	12	19	11900
(iii)	100	0	1000	14,6	16	16	13000	14,6	16	16	13000
(iv)	50	0	170	12,9	14	17	12400	12,9	14	17	12400

All those situations make sense as they occur for real. Considering the results of the prices on Powernext, Belpex and APX-NL since the beginning of the TLC, we build the "Fig. 7," for which market 1 corresponds to France, market 2 is Belgium and market 3 stands for The Netherlands.

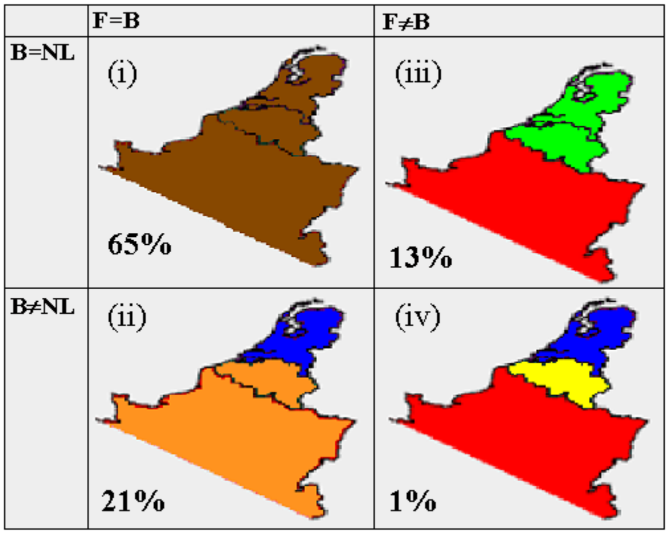

Fig. 7. Actual situations from nov 2006 to jan 2009

Comparing the results obtained with both models, using six input data situations, we can assess that both models are relevant and lead to the same results. Moreover, we can assert that market coupling does actually lead to the optimal allocation of cross-border capacities.

However, those two models have their own advantages and drawbacks:

- the sequential model illustrates the way the TLC actually works. Moreover, the input data are made up of Net Export Curves (NEC) and then it does not need all the information contained in the offers and bids from the participants of each national market. Finally, this model can be used to simulate any three-market coupling without any structural change in the market architecture of each country. However, it is rather difficult to extend this model to a larger perimeter, as the number of interfaces raises quadratically with the number of involved countries. Thus, the number of cases to handle shall be difficult to set in a sequential model. Besides, the calculation of the ATC on each interfaces gets much more complicated, and needs a high level of coordination between TSOs.
- on the contrary, the optimisation model can be easily extended to a system with a larger number of nodes as the objective function and the constraints to consider are the same, whatever the number of markets to take into account. Moreover, the problem is a linear and convex problem, so the computation time should not be a concern. Nevertheless, the main problem of this extension is located in the nature of the needed input data. Indeed, the optimisation relies on the whole aggregated supply and demand curves from each market as input data. As a consequence, the fact that a centralized operator has to gather and deal with the whole information from each power exchange could lead to the emergence of a global power exchange for the region, and to the possible disappearance of local power exchanges, which could take time to set up. As for the sequential model, the calculation of ATC between markets requires a high level of coordination between TSOs.

Thus, **we decided to focus on the optimisation model for the modelling of the Open Market Coupling** and we challenged our model with a four-country system (France – Belgium – Germany – The Netherlands) and various scenarios.

IV. FLOW BASED MARKET COUPLING

Despite the fact that the Market Coupling Mechanism leads to the optimal allocation of the cross-border capacities, the level of integration of the European Power Market would raise if the amount of capacities to allocate was larger. Indeed, when calculating the amount of ATC on each border, TSOs consider margins in order to take into account uncertainties and random effects on the neighbouring networks. Finally, the conversion from physical limits on the equipments to commercial capacities is a key point of the whole mechanism and a way of improvement could be a flow-based Market Coupling. We built a variant of the optimisation model in order to model the principles of a flow-based Market Coupling. The objective function is the same as the one for the former model, whereas the constraints are linked to the respect of physical constraints according to actual power flows on the network assets and relying on the zonal Power Transfer Distribution Factors (PTDF) that represent the impact of a transaction on each transmission line.

Zonal PTDF are calculated, choosing a slack node[8] among the nodes of the zonal network. $PTDF^{p}_{m\to n}$ is the fraction of the power flow on the line between m and n calculated, according to Kirchhoff's laws, induced by the increase of the balance of the country p by 1MW and the decrease of the balance of the slack zone by 1 MW.

In the flow-based optimisation model, the line between countries m and n is represented with a maximum allowable flow $Flow_{MAX(m,n)}$ and an estimated flow $T_{0,m\to n}$ which is present prior to the additional transaction. Moreover, transactions from market p to market q, and from market q to market p (represented respectively with the variables $Exp_{(p,q)}$ and $Exp_{(q,p)}$) are considered as variation around the initial balance $\overline{B}p$ of the concerned country p.

The resulting flow on a cross border transmission line between countries m and n is represented by a variable $Flow_{(n,m)}$. The opposite flow $Flow_{(m,n)}$ is equal to $-Flow_{(n,m)}$.

The new transmission constraints in our optimisation problem are defined in (6), where p is a country among the power system Z.

$$\begin{cases} Flow_{(m,n)} = T_{0,m\to n} + \sum_{p\in Z} PTDF^{p}_{m\to n} \times \left(\overline{B}_p + \sum_{q\in Z} \left(Exp_{(p,q)} - Exp_{(q,p)} \right) \right) \\ Flow_{(m,n)} \leq Flow_{MAX(m,n)} \end{cases} \quad (6)$$

The values of the zonal PTDF used in the model are the result of a multi-linear regression between the flows on given interconnections and the net production of the countries involved in the PTDF calculation (by net production, it is meant supply minus demand). The input data for this calculation are observed data[9], averaged on the year 2006.

We built a base case, which consists in constructed supply and demand curves based on historical data, and price quotations. Regarding the prices, the scenarios are based on futures' prices. Concerning the quantities traded in each market, we base our argument upon historical data from the day-ahead markets.

We assumed that the demand curve is the symmetric of the supply curve. Indeed, on the day-ahead market, only the marginal part of the production and consumption is represented. This part is managed by traders, and we could say that the demand curve is in fact a "non-production" curve: it represents the energy a trader prefers to buy instead of produce.

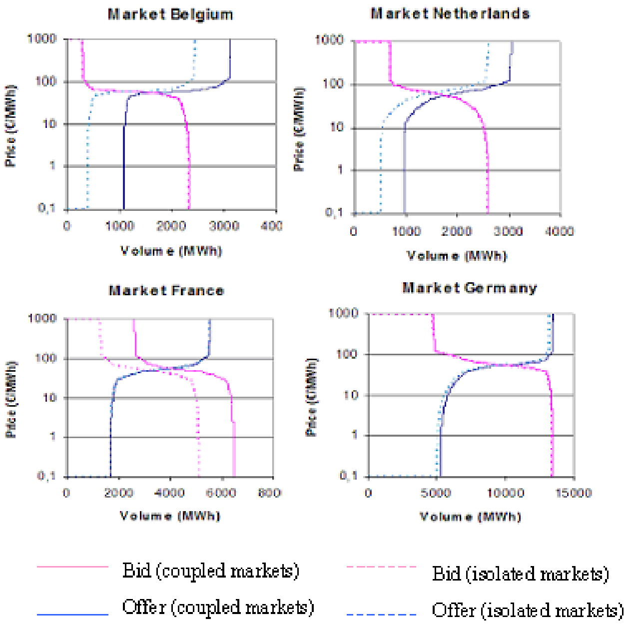

Fig. 8. Bids and Offers curves in the Base Case

The ATC between countries are based on the Etsovista data. We assumed that the ATC is equal to one third on the Net Transfer Capacity[10].

The $Flow_{MAX}$ are based on the maximal flows observed on each interface on a large number of real situations occurred in 2006.

We built six scenarios - that rely on the same data framework that corresponds to the base case - in order to represent several actual situations and we compared the results obtained using both optimisation models.

Scenario (0) corresponds to the Base Case.

Scenario (1) is a scenario with a Wind Peak in Germany, that consists of an additional production of 6000MW in Germany. We assumed that wind forecast allow half of the quantity to be contracted outside the day-ahead market. Therefore, we subtracted 3000 MW from the demand curve, and we added 3000 MW to the supply curve.

Scenario (2) stands for a situation of cold peak in France. Here we consider an increase of 4000 MW of demand, but we suppose only half of it is traded on the day ahead power exchange, assuming that the other part is contracted bilaterally. Therefore, we subtract 2000 MW from the reference demand curve, and we add 2000 MW to the reference supply curve.

Scenario (3) is the opposite of scenario (1) with lack of wind in Germany. It leads to a decrease of production up to 4000 MW and increases the German price. Half of this amount has been contracted outside the day-ahead market. Therefore, we subtracted 2000 MW from the demand curve, and we added 2 000MW to the supply curve.

Scenario (4) corresponds to a raise of the Natural Gas price. The French price is not changed, since the marginal production is more made of coal plant in France. However, the

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[8] In our zonal approach – a node corresponds to a country. The choice of the slack node doesn't matter.

[9] Collected on www.etsovista.org

[10] The other two third are assumed to be allocated through monthly and annually explicit auctions.

German, Belgian, and Dutch prices are affected. In those countries, the part of gas in the marginal production is different: the price is increased by 15€/MWh on the German market, 25€/MWh on the Belgian market and by 30€/MWh on the Dutch market.

In scenario (5), we supposed an incident on the network lines between Belgium and the Netherlands. Half of the transmission capacity between those country is unavailable.

Scenario (6) is a combination of scenarios (1) and (5).

The results using both optimisation model are given below.

TABLE II

SIMULATION RESULTS FOR THE SEVEN STUDIED SCENARIOS

	Isolated markets	**ATC based model**	**Flow based model**	**Social welfare evolution**
(0)	$P_F=50$ $P_G=55$ $P_B=58$ $P_N=62$	$P_F=P_B=P_N=P_G=55$	$P_F=P_B=P_N=P_G=55$	identical
(1)	$P_F=49{,}9$ $P_G=37{,}5$ $P_B=58{,}2$ $P_N=62{,}4$	$P_F=P_B=P_N=49{,}4$ $P_G=46{,}7$	$P_F=P_B=P_N=P_G=48{,}2$	increase
(2)	$P_F=95{,}9$ $P_G=55{,}5$ $P_B=58{,}2$ $P_N=62{,}4$	$P_G=P_B=P_N=58{,}7$ $P_F=61$	$P_F=P_B=P_N=P_G=59{,}1$	increase
(3)	$P_F=49{,}9$ $P_G=66{,}2$ $P_B=58{,}2$ $P_N=62{,}4$	$P_B=P_N=60{,}8$ $P_F=P_G=58$	$P_F=P_B=P_N=P_G=59{,}5$	increase
(4)	$P_F=49{,}9$ $P_G=63{,}4$ $P_B=69{,}1$ $P_N=77{,}4$	$P_G=P_B=P_N=61{,}4$ $P_F=59{,}6$	$P_F=P_B=P_N=P_G=61$	increase
(5)	$P_F=49{,}9$ $P_G=55{,}5$ $P_B=58{,}2$ $P_N=114{,}6$	$P_G=P_B=P_F=56{,}5$ $P_N=62{,}2$	$P_F=P_B=P_N=P_G=56{,}6$	increase
(6)	$P_F=49{,}9$ $P_G=37{,}5$ $P_B=58{,}2$ $P_N=62{,}4$	$P_B=P_N=52{,}4$ $P_F=50{,}2$ $P_G=44{,}4$	$P_F=48{,}5$ $P_G=46{,}7$ $P_B=51{,}3$ $P_N=51{,}7$	increase

The first column gives the prices of each market considered as isolated, the second one the prices obtained through the ATC based optimisation, the next one the prices given by the flow-based optimisation and the last one the evolution of the social welfare from the ATC based model to the flow-based model.

We can notice that, in scenarios (1) to (5), only the flow-based method leads to a single price and the social welfare has increased. On the other hand, as described in the scenario (6), once there is a physical congestion on a line, four different prices are obtained with the flow-based approach, whereas with the ATC-based approach, the price in the Belgian zone is the same as the one in the Dutch zone, and there are only three different prices.

In each scenario, the social welfare is more important with the flow-based approach than with the ATC based approach. Indeed the ATC is calculated with margins in order to guarantee that commercial capacity offered on an interface is independent from the transit on any other interface. On the contrary, taking into account the actual limits on the network allows actors to use the network infrastructure at its maximum.

V. CONCLUSION

Firstly, the need for the NECs in the sequential model or the need for the supply and demand curves for the optimisation model raises the question of the degree of information which should be shared between countries, and stresses the need for a centralisation of this information. Moreover, the sequential model is rather difficult to extend this model to a larger perimeter, as the number of interfaces raises quadratically with the number of involved countries.

Besides, comparing results obtained with both optimisation models (ATC based vs Flow based) we can assume that taking into account physical limits instead of commercial limits leads potentially to a more optimal use of the transmission lines capacities, but have some drawbacks due to the complex physical reality which is inherent to the model. Table 3 sums up the drawbacks and advantages of ATC based vs flow based capacity allocation. We assume that the flow based approach shall be a good solution for the future, provided that its drawbacks are seriously managed.

TABLE III

ATC BASED VS FLOW BASED – DRAWBACKS AND ADVANTAGES

	ATC based	**Flow based**	**Remarks**
Capacity maximisation	-	++	Less need for margins
Security	-/+	+	ATC guarantee safety, but don't take into account parallel flows
Operation experience	+	-	
Easiness to understand the limits induced by the network	+	-/+	ATC are easy to understand Flow based need easy guides
Difficulties linked to coordination between TSOs	-	--	

VI. ACKNOWLEDGMENT

The authors would like to thank M. Dupuy for her contributions.

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