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Effect of Integrating Regulating Power Markets of Northern Europe on Total Balancing Costs

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***Abstract*-- Integration of regulating power markets of different balancing regions has a potential to reduce the costs of balancing within multinational power markets by exchange of regulating power between these regions. Currently, most regulating power markets are operating on a national level so that exchange of regulating power between regions is minimal. This paper investigates the potentials for reduction of total balancing costs by creation of multinational regulating power markets studying the case study of Northern Europe; the Netherlands, the Nordic region and Germany. An optimization model is built to analyze the effects on total balancing costs – the costs paid by a multinational TSO to the providers of regulating power. Based on the numerical results, total balancing costs can decrease by 100 million Euros per year when enough interconnection capacity is allocated to balancing trade. Furthermore, total amount of activated regulating power is reduced due to supportive power exchange. Finally, the use of the uniform pricing mechanism leads to frequent congestion of interconnection lines due to balancing trade. On average, regulation power prices stay within the same range.**

***Index Terms*— Frequency control, international trade, optimization methods, power system security.**

I. INTRODUCTION

BALANCING is a (near) real-time power system operation function conducted by the Transmission System Operator (TSO) that handles the balancing of electricity supply and demand in a power system. The market-based balance management mechanism (Balancing Market) in a power system is a set of institutional arrangements operated by the TSO that creates market-based balancing of the system. It generally consists of three main elements: balance responsibility, imbalance settlement, and balance regulation. The first two make sure that there are market parties responsible for balancing their schedules (balance responsible parties) and that they will have incentives to minimize their imbalance, by charging a financial penalty to any imbalance. Balance regulation handles the provision of regulating power needed to resolve system imbalances by market parties – the balance providers. In a regulating power market, balance providers submit regulating power bids with a certain bid volume and bid price that are activated in merit order by the TSO when needed for system imbalance resolution. Most countries have nowadays a national balance management mechanism and also regulating power market, and therefore there is not much exchange of balancing services between balancing regions. During recent years, there have been many discussions at the international level regarding facilitation of cross-border balancing exchanges and creation of integrated multinational balancing markets in order to use balancing resources in a more regionally efficient way.

European Regulators Group for Electricity and Gas-ERGEG provides guidelines of good practice for electricity balancing markets integration which consists of general policy-related recommendations on design of integrated balancing markets with special emphasis on improvement of operational security of the system, efficient allocation of cross-border capacities, and market efficiency and competition [1]. Union of the Electricity Industry-EURELECTRIC advocates a sequential approach in order to achieve integration of intra-day and balancing markets across borders [2]. The report mentions the need for establishment of national and cross-border “intra-day” markets, and in parallel, introduction of market-based procurement mechanisms for reserve and balancing power with sufficient harmonization of the key issues of these markets in order to allow, as a further step, the cross-border optimization of balancing markets [2].

European Transmission System Operators-ETSO focuses on facilitation of cross-border tertiary control services and analyzes the consequences of the steps in integration of the corresponding markets considering four different models (related to different levels of cooperation/integration) [3]. Although the report mentions that it is extremely difficult, if not impossible, to quantify these effects, it recognizes main challenges in markets integration to be product incompatibility, differences in price structure, and differences in procurement mechanisms of system operators of different systems, and emphasizes the harmonization needed in market design issues and calculation of imbalance prices [3]. Furthermore, ETSO envisages an evolving regional harmonization and integration process enabled by a cooperation agreement between the TSOs in the region and supported by changes in existing legal, regulatory and inter-

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TSO arrangements as far as necessary [4]. Based on previous reports, EURELECTRIC analyzes the balancing markets integration problem in more depth and focuses on the design of markets for procurement of balancing services and proposes a design model for the capacity and energy markets of balancing services without any distinction between different services with different characteristics [5].

Beside the literature reviewed above, which concerns high level policy-related guidelines and recommendations on balancing markets integration as a single problem, comprehensive studies addressing various technical, institutional and economical challenges of integration of national balancing markets are missing. Since, in contrast to wholesale electricity markets, e.g. day-ahead markets, balancing markets are not single markets with one single product to be traded in the market, the process of integration is much more complicated and every element of balancing markets needs to be studied and analyzed separately in more details. This paper is focused on the markets for procurement of regulating power (as the main service procured to balance the system) and investigates the economical value of integration of national regulating power markets. We analyze the potential reduction of balancing costs (a component of system security costs) as the result of integrating separate regulating power markets at the national level in order to create multinational integrated markets for procurement of regulating power.

The structure of the paper is as follows: In section II the issue of regulating power market integration is described in more detail. Section III provides a description of the optimization model built and used to analyze the effects of the integration with. Section IV provides the model results and finally, in Section V the conclusions are presented.

II. Regulating power market integration

Regardless of differences in terminologies and definitions used in different systems, based on objectives of the activation of services and the general response speeds, three main types of services used to maintain balance between load and generation can be identified in all power systems [6, 7]:

a) *Primary Control Service* which is a local automatic control that adjusts the active power generation of generating units to quickly restore the balance between generation and consumption within the synchronous area, using turbine speed or turbine governors. In particular this control is designed to stabilize frequency after large generation or load outages, and therefore it is indispensable for the stability of the system.

b) Secondary Control Service which restores the balancing area's frequency and interchanges with other areas to their target values following an imbalance, without impairing the primary control that is operated in the synchronous system in parallel but by a margin of seconds. While primary control limits and stops frequency deviations, secondary control brings the frequency back to its nominal value. Secondary control makes use of a centralized generation control, modifying the active power set points/adjustments of the generation sets in the time frame of seconds to typically around 15 minutes.

c) Tertiary Control Service refers to manual changes in dispatch and commitment of generating units. Tertiary control resources may directly be used to restore the balance between generation and consumption when secondary control is unable to maintain the balance (sufficient secondary reserve is not available in case of large contingencies). The activation time of tertiary control services varies from several minutes to hours.

Regulating power is the balancing service related to secondary control and can be activated automatically (in case of AGC), or manually. Primary control service is mainly deployed for capacity purposes that is aimed at insuring security of the system and delivers only a marginal amount of energy in real time, because the time length of the service deployment is in the matter of seconds and it is quickly replaced by activation of other slower resources such as regulating power (secondary control). On the other hand, tertiary control service is procured in order to relieve congestions in the network, to replace other balancing resources and in case of insufficient secondary control to recover system's frequency (severe contingencies) as a balancing resource to balance the system. Thus, secondary control is the main type of balancing service aimed at resolving imbalances in the system and delivers significant amounts of energy in real time. Balance providers submit their bids for regulating power (the product to be traded in the market) to the regulating power market and the system operator, as the single buyer entity, buys the required amount of regulating power based on the needs of the system (volume and direction of imbalance).

Upward regulating power is the regulating power provided by increase of production or decrease of consumption and is needed when the system imbalance is negative, or the system is 'short'. Downward regulating power is the regulating power provided by the decrease of production or increase of consumption and is activated when the system imbalance is positive, or the system is 'long'.

Activation of bids from the bid ladder (a virtual scheme in which regulating power bids are ordered) in price order means that bids with the lowest bid price of upward regulating power and the bids with the highest bid price of downward regulation power are activated first. This is because providers of upward regulation are paid by the TSO, while providers of downward regulation pay the TSO (unless the regulation price is negative).

The "regulation price" is the price with which activated regulating power is settled in a regulating power market. In a time period where only upward regulating power has been activated an upward regulation price can be determined based on the pricing mechanism used (marginal or pay-as-bid); the same holds for downward regulation.

The value of regulating power market integration is expected to lie mainly in the direction of balancing costs reduction. This cost reduction can be expected because of the exchange of regulating power between balancing regions, since regulation resources will be used in a more regionally efficient way and the cheapest regulating power bids can be selected on a multinational level. In addition, exchange of supportive power can also reduce balancing costs. Supportive power exchange is interregional power exchange that offsets the regional imbalance of both the importing and the exporting country, and which does not require any activation of regulating power bids. In other words, when one region is long and the other is short, the surplus power can flow to the region with the power shortage, when enough interconnection capacity is available. We will use the term "balancing trade" to indicate the interregional exchange of both regulating power and supportive power.

III. MODEL DESCRIPTION

The case study to be analyzed is regulating power market integration of three balancing regions within Northern Europe (the Netherlands, the Nordic region and Germany). We have considered in the model a fully integrated regulating power market, where only one entity (a multinational TSO) has access to all regulating bids in the system and decides which bids are activated. At each time unit, the three regions have a certain national imbalance, which must be resolved by activation of regulating power. Our goal is to find the optimal set of activated balancing power in each of these areas that minimizes the total balancing costs.

We formulated the problem of minimizing total balancing costs in the considered areas as an optimization problem with total balancing costs as the objective function. Total balancing costs is the sum of individual costs in each area which is calculated as the product of the activated regulating capacity and regulation price.

The prices are calculated using uniform pricing (like is already used in the common Nordic regulation power market). Uniform pricing is based on the following principles:

- If there is no congestion or only one line congested[1], a uniform price is used for the whole system which is the highest price among the national prices for activated upward regulating power, and the lowest price among the national prices for activated downward regulation power.
- If two lines are congested, the system is split into two price areas.
- If all three lines are congested, the system is split into three price areas.

Several constraints have been applied to the optimization model.

a) All countries must be balanced as a result of activation of regulating power.

b) The maximum interconnection capacity available for balancing trade should not be violated.

c) The activated capacity in a country is not unlimited.

Control variables of this optimization problem are regulating power activated in each area and the interconnection transfers related to the trade of regulating power.

[1] If one line is congested, all three areas are still connected to one another with non-congested lines.

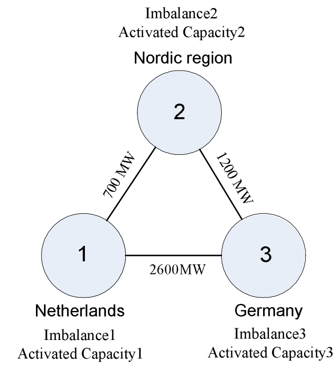


Fig. 1. Illustration of the modeled system

The modeled system consists of three balancing regions; the Netherlands (area 1), Nordic region (area 2), and Germany (area 3), and three interconnection lines; one in between each pair of regions. Figure 1 illustrates the system.

Interconnection line 12 (from the Netherlands to the Nordic region) is the Nor-Ned cable, which has a capacity of 700 MW. The capacity assumed for interconnection 23 is the sum of two interconnection capacities between Germany and the Nordic region: Germany-Sweden (600 MW) and Germany-Eastern Denmark (600 MW). The capacity for Interconnection 13 is based on the capacity between the Netherlands and Germany available for power trade which is 2,600 MW.

To include national imbalance volumes into the model, we derived two imbalance volumes for areas 1 and 3 (one positive and one negative for each area), and three imbalance volumes for area 2 (one positive, one negative, and one zero). These volumes are based on real historical data on the activated secondary control capacity from year 2007[2]. To obtain the negative imbalance volume, we took the average of the activated upward regulation. The percentage of the times that upward/downward regulation was activated is used as the probability of occurrence of the negative/positive imbalance. For the Nordic region, we found that during 20.6% of the time, there was no regulation power activated at all (no imbalance). Table I shows the national imbalance volumes derived, and their corresponding probability of occurrence.

Based on the national imbalance volumes and probabilities of occurrence shown in Table I we composed twelve cases which incorporate all possible combinations of national imbalance volumes. The accompanying probability for this case is the product of the corresponding probabilities of occurrence of each national imbalance. Therefore, imbalance resolution is represented during a whole year with these twelve cases. See Table II.

[2] Data retrieved from the web sites of Nord Pool (www.nordpool.org), Statnett (www.statnett.org), TenneT (www.tennet.org), RWE (www.rwe-transportnetzstrom.com), EnBW (www.enbw.com), Vattenfall (www.vattenfall.de), and E.On (www.eon-netz.com). Websites visited in June 2008.

TABLE I
NATIONAL IMBALANCE VOLUMES AND THEIR PROBABILITY OF OCCURRENCE

	National imbalance volumes (MW)			Probability of occurrence (%)		
Netherlands (1)	+90	-85		55.4	44.6	
Nordic region (2)	+270	-385	0	32.7	46.7	20.6
Germany (3)	+550	-570		59.7	40.3	

TABLE II
THE TWELVE DIFFERENT CASES – NATIONAL IMBALANCE VOLUMES AND PROBABILITY OF OCCURANCE

cases	1	2	3	4	5	6	7	8	9	10	11	12
Netherlands	-85	90	-85	-85	90	-85	90	90	-85	-85	90	90
Nordic reg.	-385	-385	270	-385	270	270	-385	270	0	0	0	0
Germany	-570	-570	-570	550	-570	550	550	550	-570	550	-570	550
Probability	0.08	0.10	0.06	0.12	0.07	0.09	0.15	0.11	0.04	0.05	0.05	0.07

IV. MODEL RESULTS

The main objective of this analysis is to investigate the effect of regulation power market integration in the mentioned countries on the total balancing cost of the resulting integrated system. The change of total balancing costs depends on the possibility of transferring regulating power between these countries through interconnection lines. Therefore, the amount of interconnection capacity available for balancing trade plays a decisive role in the economical value of the resulting integrated regulating power market.

Figure 2 shows total annual balancing costs (taking into account the twelve different cases and their probabilities of occurrence) as a function of percentage of the total interconnection capacities between these countries that is available for balancing trade. This can be the interconnection capacity not used in the day-ahead/intraday markets or the capacity allocated to balancing. One can see that the total annual balancing cost before regulating power market integration is about 180 million Euros per year (corresponding to no interconnection available), and drops down below 100 million Euros per year when 10% of interconnection capacity is available for balancing. This means a balancing cost reduction of about 80 million Euros per year.

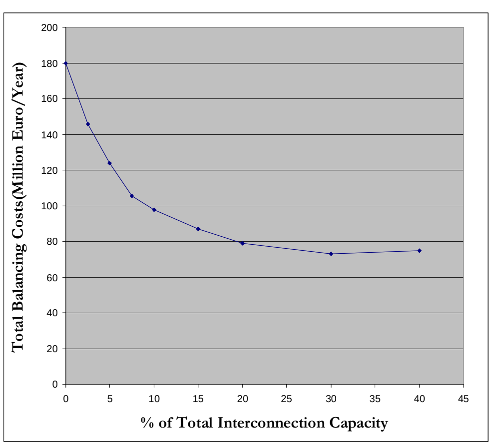


Fig. 2. Total annual balancing costs

As can be seen from the figure, total balancing cost reduces with a much higher rate in the beginning and after 30% the total cost is constant. It means that there is enough interconnection capacity for transferring balancing power between the three areas and the minimum point has reached, so increasing the interconnection capacity available does not help to reduce balancing costs.

The change of balancing costs in terms of interconnection capacity available is totally different for different cases. As an example, in Figure 3 the balancing costs are represented for cases 2 and 4, both in Euros per hour and in million Euros per year. This last unit only serves to enable a comparison with the total annual balancing costs (shown in Figure 2); it is not realistic since we have represented one whole year with twelve cases (twelve set of imbalances) so it is not possible to calculate the annual cost with just one case. For case 2 the balancing cost decreases after regulating power market integration, but this cost appears to rise again after 7.5% of interconnection capacity made available for balancing trade. This is caused by the uniform pricing mechanism: the integration makes the exchange of supportive and regulating power possible, but when there is no congestion, the uniform marginal price will lead to higher regulating prices (higher total cost) than in case of congestion. This happens because of the jump of prices in cheaper areas to the prices in expensive areas when there is no congestion (more interconnection is made available).

The analysis shows that using this pricing mechanism, in order to minimize the total balancing costs the optimizer tends to congest some interconnection lines to have different prices in different areas and to avoid activating this pricing mechanism which leads to jump of prices in cheaper areas. So there might be some unnecessary congestion created by re-routing balancing power as a result of the pricing mechanism.

For case 4, the costs reduction can be explained for a large part by the exchange of supportive power. In this case, there is a total negative imbalance of -470MW in the Netherlands and the Nordic system, and a positive imbalance of +550MW in Germany. If enough interconnection capacity is available, there will be a possibility of 470MW supportive power exchange from Germany to the other two areas which will offset national imbalances and will lead to a net imbalance of +80MW which will be resolved by procuring 80MW of downward regulation from the cheapest resources in the system. Finally, in both cases there is no congestion anymore when 30% or more interconnection capacity is available to balancing trade, which means that the cost reduction potential from balancing trade has been reached; the cost value does not change any further.

Figure 4 illustrates the activated regulating power in different areas for cases 4 and 10. Similar to balancing costs, the actual capacities activated for production of regulating power differ per case and per percentage of interconnection capacity allocated to balancing trade. In Figure 4a, one can see an example of reduction of regulating power activation as a result of increasing exchange of supportive power.

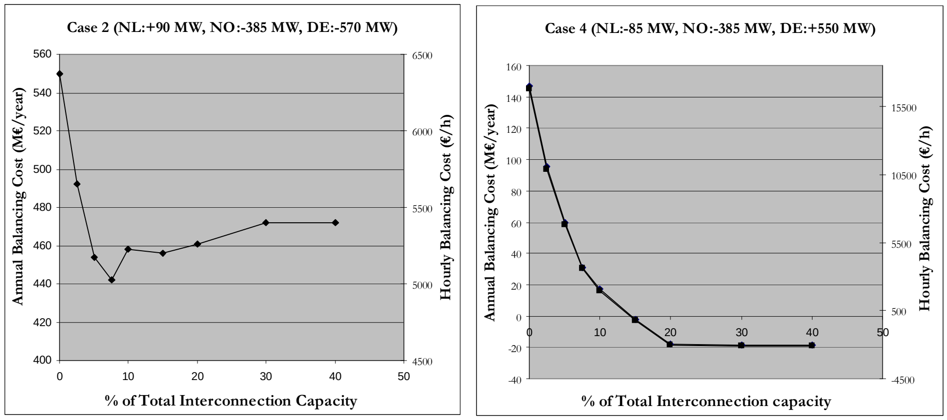


Fig. 3. Total annual and hourly balancing costs for a) case 2 and b) case 4

As can be deduced from Table II there is a potential for supportive power exchange of 470 MW in case 4, which is the largest for all cases. The available interconnection capacity enables transfer of supportive power that offsets national imbalances with a low activation of regulating power in total. The remaining +80MW of imbalance in Germany is resolved by activation of downward regulation power from the Netherlands. In case 10, on the other hand, the potential for supportive power exchange is only 85 MW. However, considerable regulating power trade occurs also in this case, as can be seen from the changing activated capacities in Figure 4b. In this case, the main needed downward regulating power is exported from the Nordic region, and to a smaller extent from the Netherlands, to Germany. This is because of high downward regulation prices in the Nordic region (cheapest resources for downward regulation) compared to Germany. For 20% and 30% there is no congestion anymore and all the German demand for downward regulating power is met by the other two regions.

In order to investigate the effect of integration on the activated regulating power and related regulation prices in the three balancing areas, it is needed to differentiate between cases where upward and downward regulating power have been activated. These cases differ per region. The activated upward regulating power and upward regulation prices for each area are shown in Table III and the activated downward regulating power and downward regulation prices are shown in Table IV, both for three different percentages of interconnection capacity allocated to balancing trade.

The tables show that the total average activated regulating power decreases after regulating power market integration due to the exchange of supportive power. Furthermore, the tables and overall results show that Germany provides both much less upward and downward regulating power when there is more opportunity for balancing trade; its needed regulating power is imported from other areas. A second trend is an increasing provision of downward regulation by the Nordic region for higher percentages. Although the amount of Nordic upward regulation power decreases from 10 to 20%, it rises again if even more interconnection capacity is available for balancing trade. The Netherlands provides both more upward and downward regulating power after the integration.

When comparing the average regulation prices from the tables it can be seen that while the upward regulation prices in the Nordic region and Germany reduce, there is an increase in upward regulation price in the Netherlands, which is because of increase of the activated power. On the other hand, for downward regulation, the prices in the Netherlands and the Nordic region decrease (less profit for the system operator) and the price in Germany has a relatively small increase.

To conclude on the change of activated regulating power and regulation prices after integration, one can see that the amount of regulating power activated decreases in total, because of supportive power. The results do show some trends for the individual countries with respect to capacities and prices under increasing percentages of allocated interconnection capacity, but with different margins and continuity.

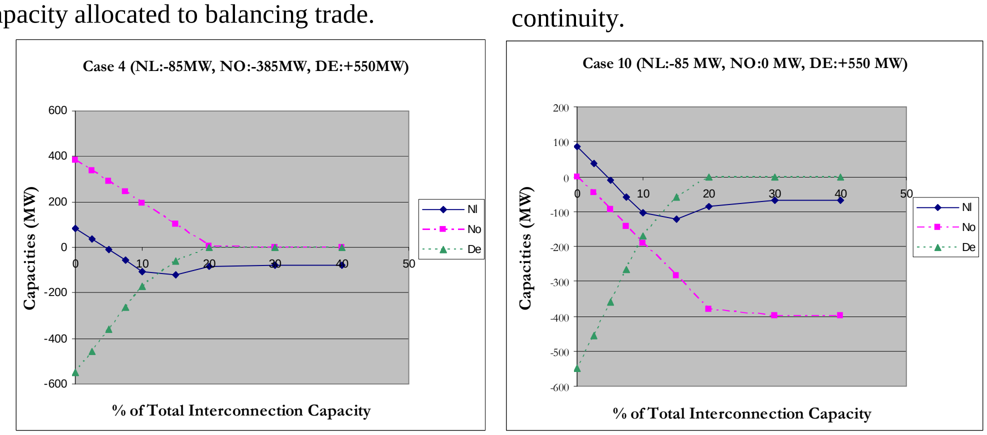


Fig. 4. Regulation power activated for a) case 4, and b) case 10

TABLE III
UPWARD ACTIVATED CAPACITIES AND PRICES OF DIFFERENT AREAS FOR THREE DIFFERENT INTERCONNECTION CAPACITIES AVAILABLE (0%, 10% AND 20%)

Upward regulation	Capacity (MW)			Price (€/MWh)		
	0%	10%	20%	0%	10%	20%
Netherlands	85	199	181	41.4	61.3	58.4
Nordic region	385	276	203	49.9	40.6	34.3
Germany	570	234	180	80.1	66.5	64.5

TABLE IV
DOWNWARD ACTIVATED CAPACITIES AND PRICES OF DIFFERENT AREAS FOR THREE DIFFERENT INTERCONNECTION CAPACITIES AVAILABLE (0%, 10% AND 20%)

Downward regulation	Capacity (MW)			Price (€/MWh)		
	0%	10%	20%	0%	10%	20%
Netherlands	-90	-122	-114	23.5	15.4	17.4
Nordic region	-270	-214	-374	37.7	41.2	31.0
Germany	-550	-296	-228	12.2	13.9	14.4

Only for Germany, with the most expensive regulation resources and typically large amount of imbalances, it can generally be said that activated capacity is reduced and regulation prices change favorably from the TSOs' point of view when more balancing trade is possible.

Finally, we give an example to analyze the effect of uniform pricing mechanism in action. Figure 5 is focused on case9; Figure 5a shows regulation prices and Figure 5b shows what percentage of the total interconnection capacity available for balancing is actually used (for all the three interconnection lines). So 100% on the vertical axis means that the corresponding line is congested.

In case 9, region 1 and 3 are short and region 2 has zero imbalance. When the interconnection capacity available for balancing is less than 10%, all the lines are congested that leads to three different price areas. But when at least 10% of the interconnection capacity is allocated to balancing trade, interconnection line 31 is not congested anymore, leading to two price areas: the Nordic region and Germany-Netherlands. So the regulation prices in the Netherlands and Germany converge at 10%. Lines 12 and 23 are still congested until 20%. When at least 30% of interconnection capacity is allocated to balancing trade, none of the lines are congested, leading to one uniform price (convergence of all prices).

After all, as Figure 5a illustrates clearly, when the 'cheapest' regions start with exporting regulating power for small percentages of allocated interconnection capacity, the regulation price of the importing country drops but the regulation price of the exporting country increases. Therefore integration of regulation power markets does not necessarily lead to lower prices in all of the three countries.

V. CONCLUSIONS

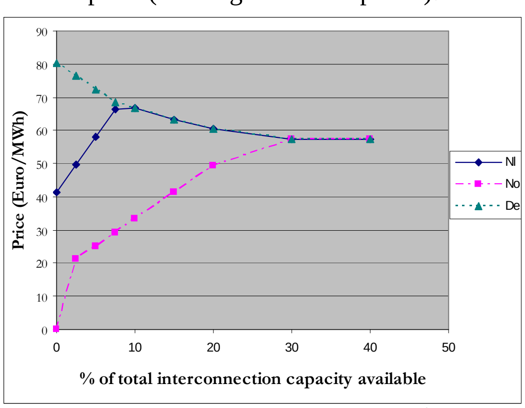
An optimization model is developed to investigate the effect of regulating power markets integration for the Nordic, Dutch and German balancing regions on the total balancing costs. By analyzing the numerical results obtained from the model the following conclusions can be made:

a) Most importantly, the total balancing costs (the money which the multinational TSO has to pay for the activation of regulating power in order to make system balanced) are greatly reduced as a consequence of regulating power market integration. This reduction has two main reasons: transfer of supportive power and regulating power trade. As expected, the reduction volume highly depends on the interconnection capacities that are available for balancing trade; annual costs reduction lies around 80 million Euros for an allocation of 10% of the interconnection capacity to balancing trades.

b) Generally, the total amount of activated regulating power decreases. This is due to the exchange of supportive power: offsetting of national imbalances without the need for activation of regulating power.

c) The amount of balancing trade increases for higher percentages of allocated interconnection capacity, which leads to lower total balancing costs. The fact that regulation prices do not improve that much (due to the pricing mechanism) is offset by the smaller need for regulating power (due to the supportive power exchange).

d) On overall, national regulation prices do not necessarily improve after integration (from a TSO perspective). Prices may decrease in some areas and increase in others (which means that some balance providers are better off, others worse), but the total balancing costs will reduce because of balancing trade. Therefore, the rules used to redistribute balancing costs to the individual areas, plays a crucial role in individual benefits of each area from regulating power markets integration.



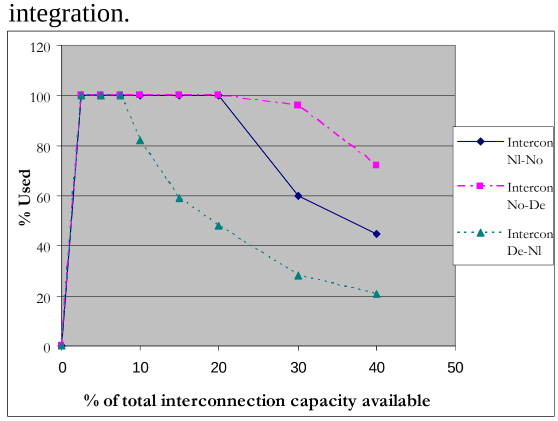


Fig. 5. a) Regulation prices (case 9), and b) percentages of available interconnection capacity that is used (case9)

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VII. BIOGRAPHIES

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