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RESERVATION OF TRANSMISSION CAPACITY FOR THE EXCHANGE OF REGULATING RESOURCES IN NORTHERN EUROPE: IS THERE A BENEFIT?

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1. Introduction

The need for sustainable energy production leads to an increasing share of wind power production especially in northern Europe, along the coast of the Northern Sea. The intermittent wind power production results in a need for regulating resources to keep the electricity system in balance. The Nordic, especially the Norwegian hydro based power production has good capabilities for offering such regulating resources, utilizing the increasing interconnection capacity between the Nordic and the continental European power system. Contemporaneously the European Union enforces the liberalization and integration of the national European power markets. In order to exchange regulating resources, a reservation of transmission capacity on the interconnections might be beneficial. Some studies, which are done on a simplified level based on a statistical analysis, show a benefit of reserving transmission capacity for the regulating resource exchange [1], [2]. However, the withdrawal of transmission capacity from the day-ahead market is not taken into account in [1]. Further on a capacity of 100MW is planned to be reserved for the exchange of regulating resources on the new Skagerrak 4 cable, connecting Norway and Denmark [3]. This paper analyzes the effects of reserving transmission capacity for the regulating power market on the links between the Nordic area and continental Europe.

2. Market designs

Aiming at a desired exchange of regulating resources between different countries, it is important to take into account the individual balancing market designs in these countries. An important point here is that these markets are compatible. The area covered in this paper's analysis is shown in Fig. 1. As discussed in [4] and [5] there are huge differences between the individual markets, especially between the continental European and the Nordic ones. One of the most important differences is the program time unit (PTU) length, being 15 min in continental Europe and 1 hour in the Nordic countries. Other important issues are the use of secondary control in continental

Europe and tertiary control in Scandinavia, and the different gate closure times. These design differences result in different bidding behaviour and market clearing results as it is shown in [5].
In order to simulate an integrated northern European regulating power market for the model which the analysis of this paper is based on, a common design for the regulating power market is assumed. This especially concerns the PTU-length and the sequence of the different markets.

Tab. 1: Modelled control areas [4]

1	Southern Norway (Statnett)
2	Middle Norway (Statnett)
3	Northern Norway (Statnett)
4	Sweden (Svenska Kraftnät)
5	Finland (Fingrid)
6	Denmark (energinet.dk)
7	Eastern Germany (50 Hertz)
8	Middle Germany (transpower)
9	Western Germany (Amprion)
10	South-western Germany (EnBW)
11	Netherlands (TenneT)

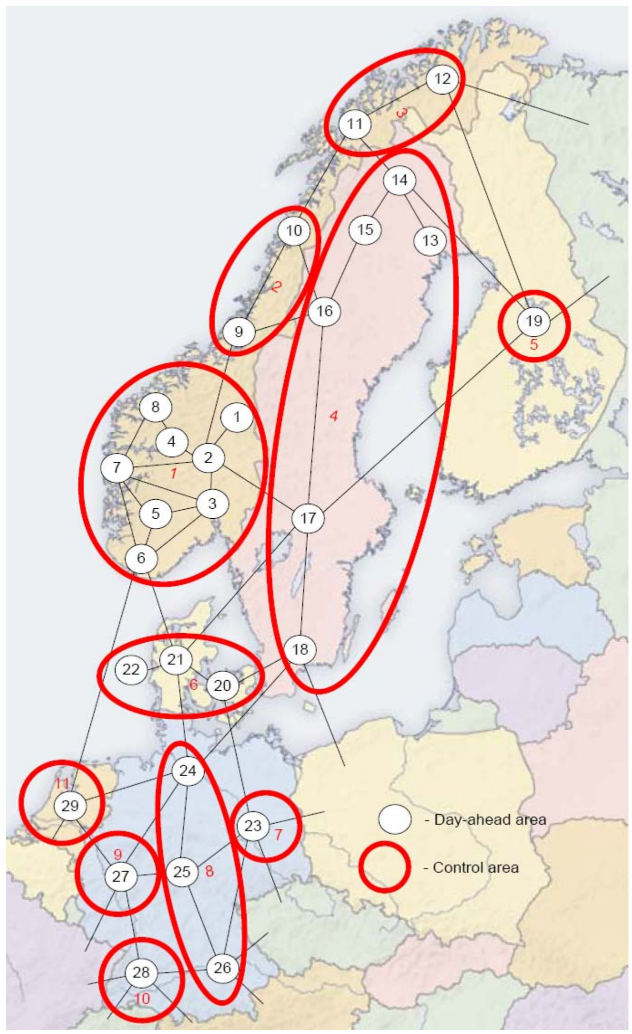

Fig. 1: Geographic overview of modelled areas [4]

3. Market model

A three stage fundamental model is used in this analysis, depicted in Fig.2, which is presented in detail in [4]. It simulates an integrated northern European regulating power market, which is based on a common day-ahead market, including the Nordic countries Denmark, Finland, Norway, Sweden and the continental European countries Germany and the Netherlands, as shown in Fig. 1.

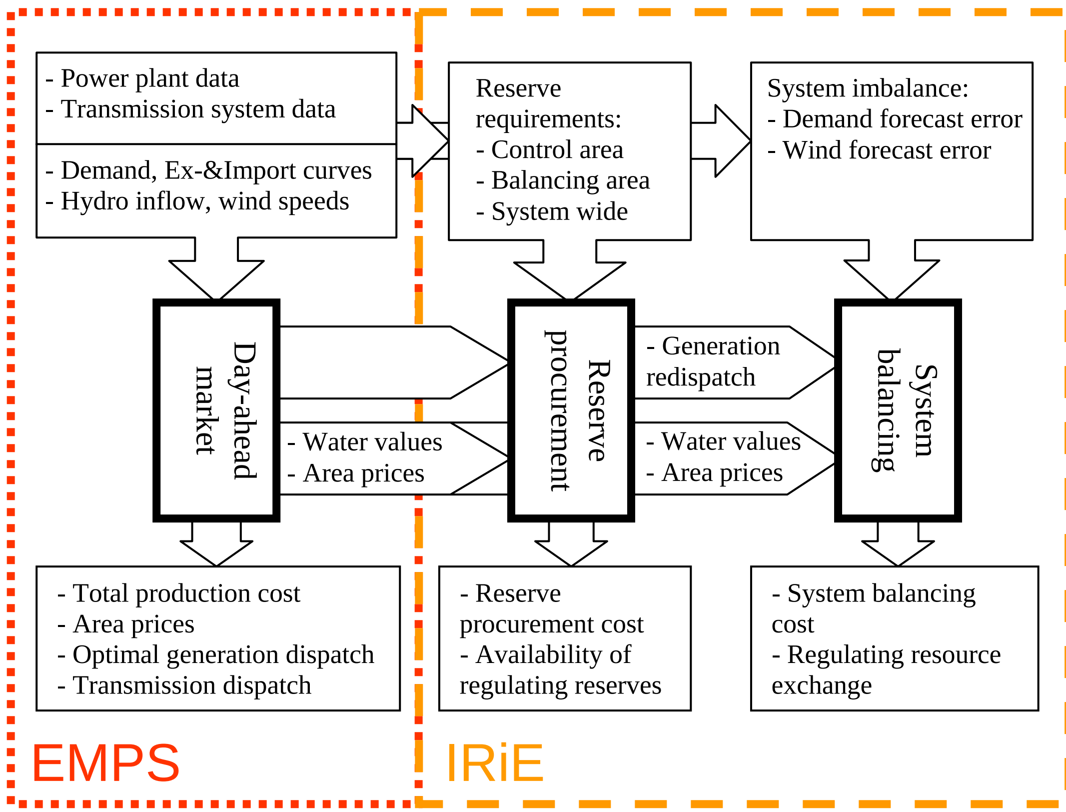

Fig. 2: Model structure and workflow [4]

The simulation is split in two general parts, represented by two different models, which are EFI's Multi-area Power-market Simulator (EMPS) and the Integrated Regulating power market in Europe (IRiE) respectively. The EMPS model represents a long- and mid-term optimisation, whereas IRiE has a short-term horizon. In the following the three subsequent steps are described in some more detail.

3.1. Day-ahead market

The day-ahead market step is implemented by EMPS [6]. This model developed by SINTEF Energy Research is a long- and mid-term optimisation model determining the socio-economic optimal dispatch of electricity generation on a weekly basis, assuming perfect market behaviour with a time horizon of several years. Weeks are divided in several subsequent periods, by which an hourly resolution of the optimisation process can be achieved.

The division in different day-ahead market areas is shown in Fig. 1. The in- and outputs of EMPS are indicated in Fig. 2. The transmission lines connecting the areas are modelled by net transfer

capacities (NTC) including linear losses. The results and output of this model is the optimal generation dispatch, area prices and the water values for the Nordic reservoirs. The water values are the opportunity costs of the stored water and are used as production costs for the hydro power plants in the subsequent steps.
A further and more detailed description of EMPS can be found in [6].

3.2. Reserve Procurement

During the reserve procurement a redispatch of the optimal generation dispatch obtained from the day-ahead market is done in order to fulfil the given reserve requirements in the control areas. This means, regulating reserves can not only be procured in the own control area, but also in other areas. As the reserve procurement is done after the day-ahead market clearing, the remaining transmission capacity is taken into account. The reserve procurement is done for each individual hour, taking into account start-up costs of thermal units and their reduced efficiency at partial load.
The reservation is done in a socio-economic optimal way, based on marginal production costs of the thermal units and the water values for the hydro power plants. A detailed description of the procurement process can be found in [4].

3.3. System Balancing

The third step covers the system balancing, by activating the least-cost regulating reserves in order to compensate the system imbalance. The available transmission capacities are taken into account. In order to account for the geographic spread of the analysed system, the transmission losses are included by a linear approximation. The balancing is done for each PTU using recorded imbalances from the respective control areas as an input. The costs for balancing the system are rough estimates based on the marginal production costs of thermal units and the water values for hydro units. However, the definition of balancing costs is done in a way that supports a utilization of hydro regulating reserves instead of thermal ones. A further and more detailed description of the system balancing can be found in [4].

4. Case studies

In order to answer the question raised in the title of this paper several case studies are done. As a basis for the study the previously described model is used, representing the 2008's state of the power system. The here presented analysis is made for an average year with respect to the inflow to the Nordic hydro system, which in this case is 192 TWh per annum.
The studied cases differ in the available transmission capacity for the day-ahead market. The capacity reservation is only done on lines connecting the Nordic countries and continental

Europe, which are the NorNed-, the Baltic- and the Kontek-HVDC cables and the Denmark-west / Germany AC interconnector. In the first case the full transmission capacity is offered to the day-ahead market. After the day-ahead market clearing, the remaining transmission capacity can be used for trading in the regulating power market. For the further two studied cases the transmission capacity offered to the day-ahead market on the previously mentioned lines is decreased by 5% and 10% respectively in order to reserve this capacity for the exchange of regulating reserves. The reservation is done for the exchange of up- as well as downward regulating reserves. In these cases the remaining transmission capacity after day-ahead market clearing plus the reserved capacity is offered to the regulating power market, including the reserve procurement and the system balancing. The nominal transmission capacities of the relevant lines can be found in Tab. 2.

Tab. 2: Nominal transmission of lines connecting Nordic and continental European countries

	NorNed	Baltic	Kontek	DK / DE int.
Countries	NO - NL	SWE - DE	DK - DE	DK - DE
NTC to	700	525	550	1400
NTC from	700	400	550	800

5. Results

The results of the case studies for reserving transmission capacity are shown in Tab. 3 for the day-ahead market outcome and in Tab. 4 for the regulating power market outcome. Results for the cases of full capacity available to the day-ahead market, a 5% and a 10% reservation capacity are shown in the subsequent tables. In addition the case of no integration of the northern European regulating power markets as discussed in [4] is shown as a comparison to classify the transmission reservation outcomes.

Table 3 shows that the reservation of transmission capacity and thus withdrawal of trading possibilities from the day-ahead market has a strong impact on the outcome of the day-ahead market clearing. The reservation of transmission capacity for balancing reduces the socio-economic benefit by decreasing the dispatched exchange of electricity between the Nordic area and continental Europe, by about 4% and 8%. However, the outcomes are quite different for the various market participants. A distinction must be made between Nordic and continental European participants, as there is a price decrease in the Nordic countries and increase in the continental countries. Due to this price changes, as it can be expected there is a benefit for continental producers and a loss for continental consumers. In the Nordic area the outcome is the opposite, with large losses for the Nordic producers. For the TSOs the reduction of available transmission capacity on the day-ahead market is slightly beneficial. Looking on the individual transmission lines on which capacity is reserved, it shows that there are different outcomes too. A benefit can be seen on the Denmark-west Germany interconnector. For the Kontek and the Baltic cable there is no change, whereas on the NorNed cable a loss can be seen. An explanation for benefit for the TSOs of reserving transmission capacity can be that the reservation brings the available transmission capacity to the day-ahead market closer to the optimal transmission capacity for a TSO. The income to the TSOs is the Congestion capacity cost, as defined in [7]. This income for the TSO is maximized if the available transmission capacity is 50% of the transmission capacity which is necessary in order not to have congestions on the transmission line.

Tab. 3: Day-ahead market outcome of reserving transmission capacity

	No integration	Full integration	5% reservation	10% reservation
Socio-economic outcome	-	-	-79.46 M€	-260.25 M€
Gross exchange	17.42 TWh	17.42 TWh	16.85 TWh	16.26 TWh
TSO outcome	-	-	0.038 M€	0.226 M€
Nordic producer outcome	-	-	-82.1 M€	-276.98 M€
Nordic consumer outcome	-	-	17.31 M€	37.46 M€
DE+NL producer outcome	-	-	7.53 M€	29.67 M€
DE+NL consumer outcome	-	-	-19.79 M€	-44.52 M€

In total it can be seen that there is no linear change of the economic outcome with the amount of capacity reservation. With a 10% reservation of transmission capacity for the exchange of regulating resources there is a significant higher decrease of the socio-economic benefit, as well as losses for the Nordic producers and benefits for the continental producers compared with the 5% reservation.

Tab. 4: Regulating power market outcome of reserving transmission capacity

	No integration	Full integration	5% reservation	10% reservation
Reserve procurement costs	167.47 M€	44.36 M€	39.78 M€	36.08 M€
Average reserves procured from Nordic area to DE / NL	0	1.305 GW	1.407 GW	1.431 GW
Redispatch	3111 GWh	2069 GWh	1997 GWh	1952 GWh
Balance settlement costs	119.4 M€	62.14 M€	54.29 M€	47.69 M€
Activated upward reserves	4019 GWh	3177 GWh	3111 GWh	3069 GWh
Activated downward reserves	-4131 GWh	-3284 GWh	-3211 GWh	-3165 GWh

Tab. 4 (continued): Regulating power market outcome of reserving transmission capacity

	No integration	Full integration	5% reservation	10% reservation
Net exchange	0	131 GWh	89.2 GWh	40.9 GWh
Gross exchange	0	2853 GWh	3101 GWh	3579 GWh
TSO income	0	5.63 M€	11.76 M€	16.25 M€

Tab. 4 shows the outcome on the regulating power market due to the reservation of transmission capacity. Here the outcomes for the reserve procurement as well as the system balancing are shown. By the capacity reservation the reserve procurement costs are reduced with 10% and 20% respectively, but compared to the process of integrating the markets this is only a minor benefit. The increase in the externally procured reserves is also only marginal, resulting in a minor reduction of the necessary redispatch during the reserve procurement. An explanation for it can be that normally there is already enough free capacity available after the day-ahead market clearing. In the hours where this is not the case the reservation of 5% or 10% of transmission capacity is not enough to increase the procurable reserves significantly.

The balance settlement costs are reduced by about 11% and 20% respectively by the additional available transmission capacity for the exchange of regulating resources. The reservation of capacity for balancing reduces the total activated reserves slightly by an increased netting of imbalances. The gross exchange of regulating resources between the Nordic and the continental European countries increases significantly by 10% and 25%, whereat the net exchange of regulating resources is reduced, which means that nearly as much down- as upward regulating resources are exported to continental Europe. The increase in the exchange of regulating resources results in an additional benefit for the TSOs, which is tripled in the case of reserving 10% of transmission capacity for the exchange of regulating resources.

Combining the outcome of the day-ahead market and the regulating power market shows that there is a benefit for the TSOs to reserve transmission capacity for the exchange of regulating resources. As the transmission lines are operated by the TSOs, they have an incentive for the reservation of transmission capacity, although this would reduce the socio-economic benefit significantly.

Fig. 3 shows the duration curve of the aggregated real-time exchange on the lines connecting the Nordic and the continental European area. It can be seen that in the cases of capacity reservation the full capacity of the lines is used quite seldom, about 1000 hours per annum, whereat in the case of full capacity available to the day-ahead market the full capacity is used in about 2000 hours of the year.

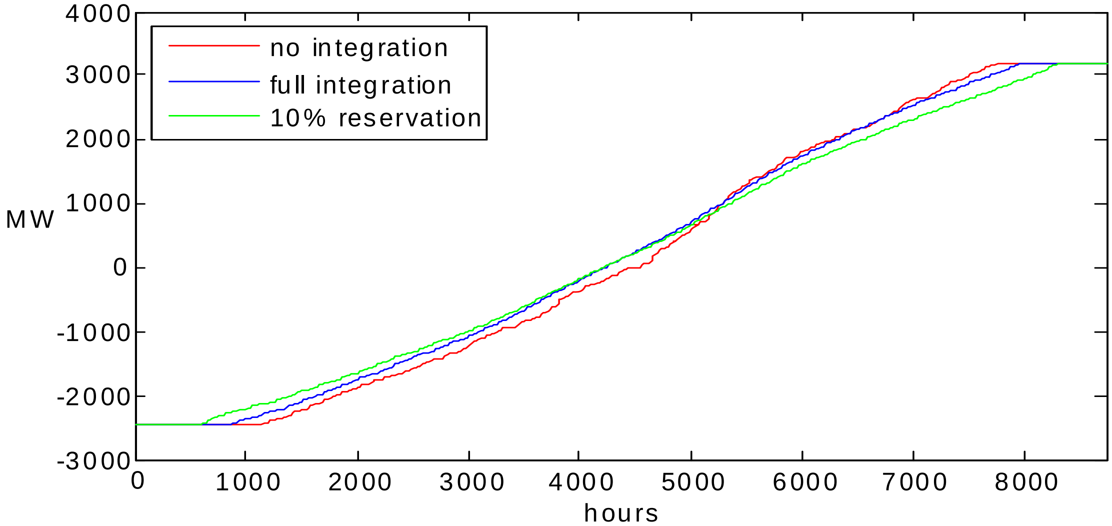

Fig. 3: Real-time exchange between Nordic and continental European countries

In Fig. 4 the duration curve of the exchange of regulating resources is shown for the different cases studied. In the case of no integration there is by definition no exchange of regulating resources. There is only a small difference between the case of full integration and the case of additional reservation of 10% of transmission capacity. The increased exchange is mainly during the hours, where there is only little exchange of regulating resources, which probably results from additional netting of imbalances. This also results in less activation of regulating reserves in the continental countries as will be discussed subsequently.

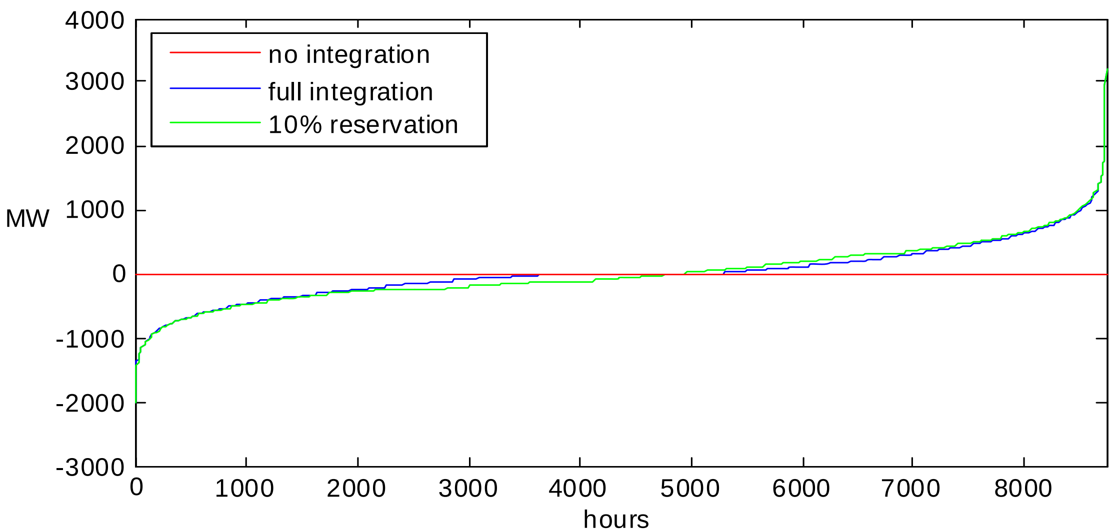

Fig. 4: Real-time exchange of regulating resources between Nordic and continental European countries

The activated reserves in the transpower area (Fig. 5) and southern Norway (Fig. 6) are depicted in duration curves below. For southern Norway there is an increase in the activation of the reserves with the integration of regulating power markets, whereas the increase due to the reservation of transmission capacity is only marginal. For the transpower area the impact is the opposite. There is a significant reduction of activated regulating reserves coming with the integration of the regulating power markets. The reservation of capacity for the exchange of regulating resources reduces such activation even more. It can also be seen that due to the exchange of regulating resources there are about 7500 hours of the year without activation of reserves in this area, which are even more in the case of capacity reservation. The increase of the time, where there is no activation of regulating reserves is due to the netting of imbalances and the activation of cheaper hydro regulating situated in the Nordic countries instead of the thermal ones in the continental countries.

The decrease of activated reserves results in a significant decrease of the expected income for participants bidding in the regulating power market in continental Europe. As regulating reserves are activated only in a few hours during a year, it becomes much more improbable for a regulating power market participant to get his bid of regulating energy accepted. Thus it becomes much harder to recover fixed costs on the plants which are used for the provision of regulating reserves by the sale of regulating energy. The procurement of regulating reserves by a capacity payment for providing regulating reserves become more important in this case, which can be used to recover the fixed cost of the power plants.

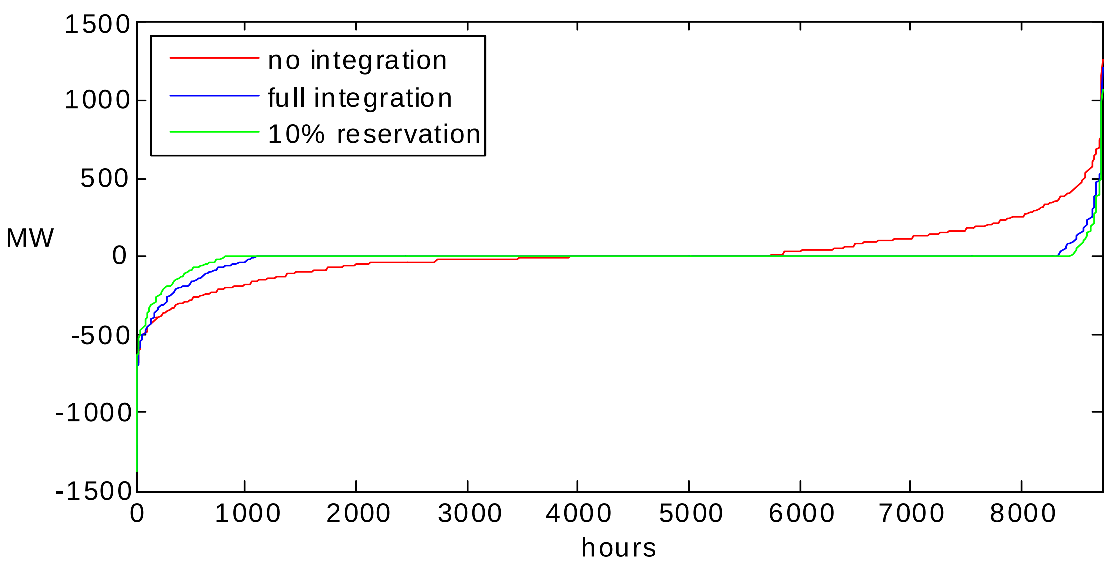

Fig. 5: Regulating reserve activation in Germany (transpower area)

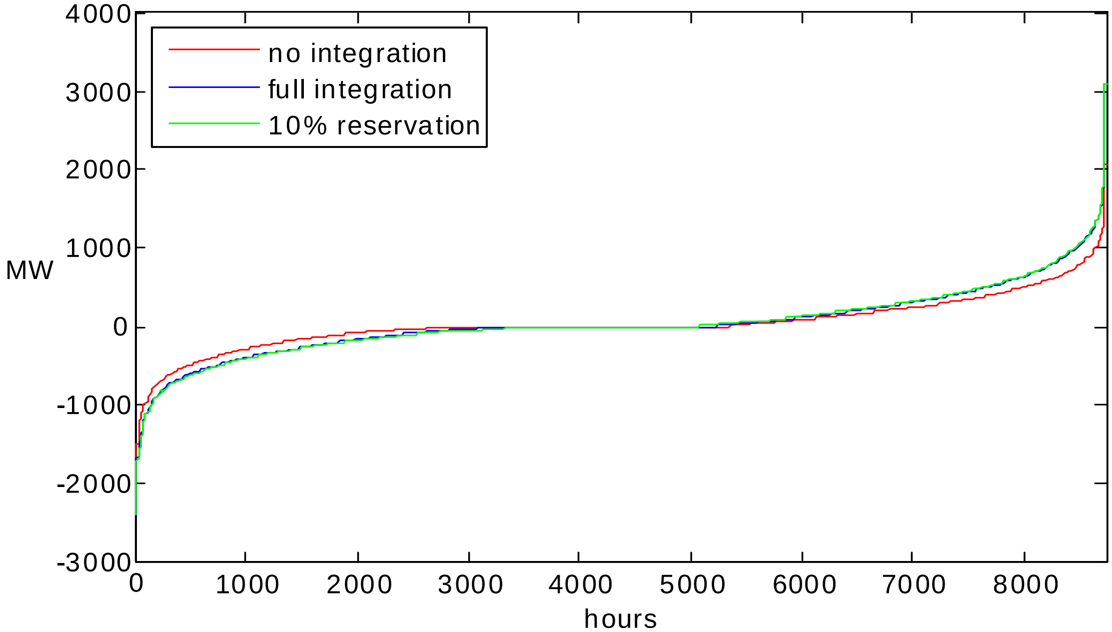

Fig. 6: Regulating reserve activation in southern Norway

In addition to the reduction of activated reserves also the maximum activated upward regulating reserves are reduced by about 200MW, whereat the maximum activated downward reserves are increased by about 300MW. This shows that a reduction of the reserve requirements in this control area would be possible.

6. Discussion

The reservation of transmission capacity has a significant impact on the day-ahead market outcome, which is shown by the utilization of the EMPS model. This model is widely used in the Nordic area for price forecasting and production planning, thus being quite reliable. On the other hand there is a reduction of reserve procurement and system balancing cost. Especially for the system balancing costs, it has to be said, that these are rough estimates, giving an indication but still being uncertain to some extend. Instead of analysing the resulting costs, the resulting exchange of reserves and regulating energy is quite reliable. It shows a high opportunity of exchanging those between the Nordic and the continental European countries.

As mentioned in [3] on the planned Skagerrak 4 connector between Norway and Denmark 100MW of transmission capacity shall be reserved in order to exchange regulating resources. It is justified by the high cost of regulating resources in Denmark. The analysis in this paper shows that by a reservation of transmission capacity the reserve procurement and system balancing costs can be reduced. However, as discussed before this reduction comes at a socio-economic loss in the day-ahead market, which mainly concerns the Nordic countries. It is stated that the trade per MW in the regulating power market is more beneficial than trading in the day-ahead market. This is validated in this paper as it is shown a capacity reservation is beneficial in total for the TSOs. Thus it can be said the statement is correct for a TSO, but not in the socio-economic perspective.

7. Conclusion

In this paper an estimation of the socio-economic outcome of the reservation of transmission capacity for the exchange of regulating reserves in the northern European area is done. The results show that a small reservation of transmission capacity increases the exchange of regulating resources significantly. This also results in a significant reduction of reserve procurement and balancing costs. However, this cost reduction is far lower than the decrease in the socio-economic benefit in the day-ahead market. Looking at different participants in the day-ahead market it turns out that the outcome of this reservation is different for producers, consumers and the TSOs. Especially for the TSOs there is a benefit of reserving transmission capacity for reserves in both the day-ahead market and the regulating power market. As the TSOs are operating the lines, the analysis suggests that it would be profitable for them to implement such a capacity reservation. This calls for an active role of the regulators in order to achieve the best socio-economic outcome. The overall decrease of the socio-economic benefit suggests that such reservation is not profitable to be implemented.

8. References

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9. Biographies

Stefan Jaehnert was born in Germany in 1981. He received his Dipl.-Ing. degree in Electrical Engineering in 2007 from the Chemnitz University of Technology. He is currently pursuing the Ph.D. degree at the Department of Electric Power Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway. His area of research interest is the integration and operation of multinational balancing markets.

Gerard L. Doorman received his MSc in Electrical Engineering from the Norwegian Institute of Technology (NTH) in 1981 and his Ph.D. from the Norwegian University of Science and Technology (NTNU, former NTH) in 2000. From 1992, he was with SINTEF Energy Research, working with hydropower optimization, energy systems analysis and market design. Presently he is a professor in electric power systems at NTNU. His current interests are the use of operations research in power systems and power markets, modelling and implementation of demand response and internationalization of balancing markets.