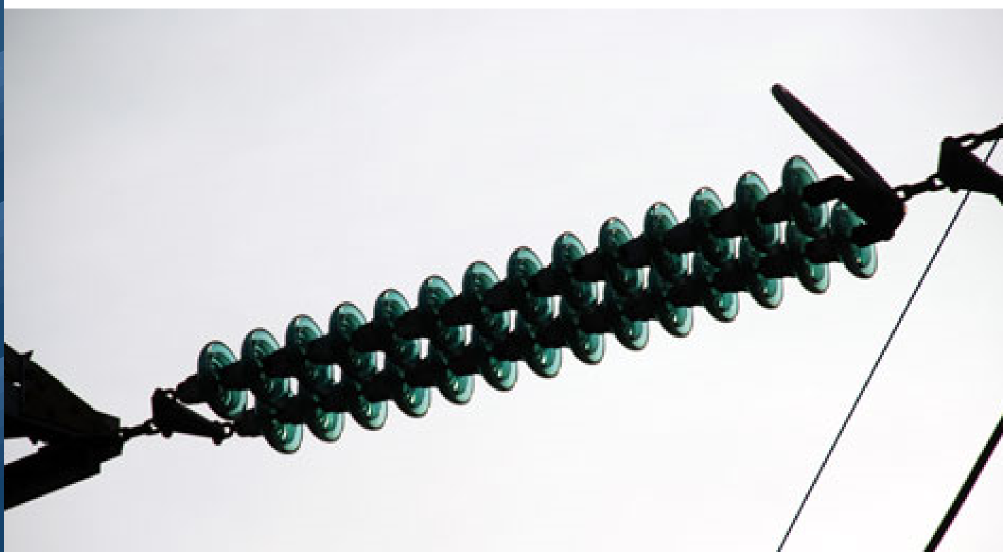
Reservation of cross-zonal capacity for balancing services

A report by THEMA Consulting Group

19
2015



RAPPORT

Reservation of cross-zonal capacity for balancing services

Utgitt av: Norges vassdrags- og energidirektorat

Redaktør: Stian Henriksen (NVE)

Forfattere: Thema Consulting Group

Trykk: NVEs hustrykkeri
Opplag:
Forsidefoto:
ISBN 978-82-410-1066-8

Sammendrag: Thema Consulting Group har på oppdrag fra NVE utarbeidet en rapport om reservasjon av overføringskapasitet for utveksling av balansetjenester.
Rapporten konkluderer med at reservasjon av overføringskapasitet for utveksling av balansetjenester vil kunne redusere de samlede kostnadene i kraftsystemet, men peker samtidig på praktiske utfordringer med å gjennomføre dette på en optimal måte.

Emneord: Balancing, balancing services, reservation of cross zonal capacity, balansetjenester, reservasjon av overføringskapasitet

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Forord

Thema Consulting Group har på oppdrag fra NVE utarbeidet en rapport om reservasjon av overføringskapasitet for utveksling av balansetjenester.

I det pågående arbeidet med utvikling av felles europeiske regler for balansemarkedene åpnes det for reservasjon av overføringskapasitet for utveksling av balansetjenester. Rapporten fra Thema Consulting Group bidrar til å gi NVE økt forståelse av problemstillingen, men reflekterer ikke nødvendigvis NVEs syn.

Rapporten konkluderer med at reservasjon av overføringskapasitet for utveksling av balansetjenester vil kunne redusere de samlede kostnadene i kraftsystemet, men peker samtidig på praktiske utfordringer med å gjennomføre dette på en optimal måte.

Oslo, mars 2015

Ove Flataker
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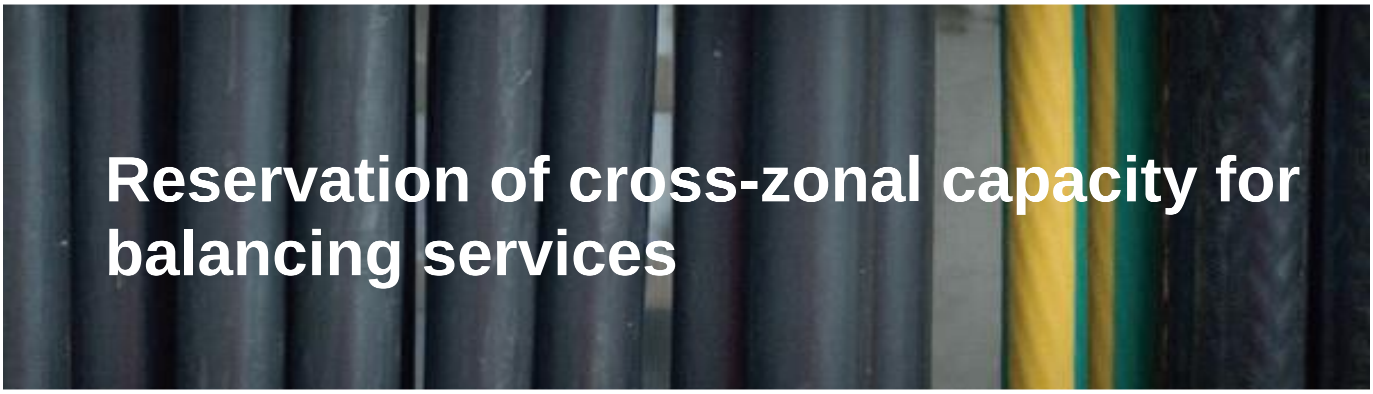
seksjonssjef

Public

ISBN nr. 978-82-93150-62-6



Reservation of cross-zonal capacity for balancing services

Commissioned by the Norwegian Water Resources and Energy Directorate

December, 2014

THEMA Report 2014-32

About the project

Project number:	NVE-14-01
Project name:	Reservasjon av overføringskapasitet til balansetjenester
Client:	Norwegian Water Resources and Energy Directorate
Project leader:	Berit Tennbakk
Project participants:	Arndt von Schemde Åsmund Jenssen

About the report

Report name:	Reservation of cross-zonal capacity for balancing services
Report number:	2014-32
ISBN-number:	978-82-93150-62-6
Availability:	Public
Completed:	December 4th, 2014

Brief summary

Exchange of balancing services is likely to reduce the cost of electricity market operation significantly. To fully reap the potential benefits, cross-border capacity must be reserved for exchange of balancing energy in real-time operation. The design of the reservation procedure is crucial for the efficiency of such reservation. The efficient solution implies simultaneous co-optimization based on real bids in the markets for day-ahead energy and balancing services, hourly reservation, harmonization of balancing product definitions, and flexibility to adjust the solution in the intraday market. Co-optimization via explicit transmission capacity auction and market-based reservation are not likely to provide efficient solutions. The potential value of reservation cannot be based on historical balancing and day-ahead prices as both increases in cross-border capacity and exchange of balancing services are likely to affect prices in both markets. In addition, the electricity market transition is likely to increase the cost of balancing and the value of exchange of balancing services between markets.

About THEMA Consulting Group

Øvre Vollgate 6 0158 Oslo, Norway Company no: NO 895 144 932 www.thema.no	THEMA Consulting Group provides analysis and advice for the transition to the future energy system. Our analysis, studies and strategic advice are based on in-depth knowledge of markets and infrastructure, broad energy and climate policy insight, long experience, and solid professional skills.

CONTENT

SUMMARY AND CONCLUSIONS

Interconnectors or Cross-zonal Capacity (CZC) can be used for exchange of energy or balancing services. Exchange or sharing of balancing services requires that CZC is available in real time operation. Both theory and model based analyses corroborate the notion that reservation of CZC for balancing services potentially increase the value of CZC. However, realization of the potential values depends on a number of market design elements.

Below, we discuss the welfare economic consequences of reservation of CZC for balancing services, and the elements that regulators should emphasize when choosing the model for such reservation. The models analysed are the co-optimization procedure and the market-based reservation model proposed in the network code on electricity balancing (NC EB).

Optimal allocation of Cross-zonal Capacity

Optimal reservation implies that the marginal value of sharing or exchange of balancing services is equal to the marginal value of exchange of energy in the day-ahead markets (DAM). The welfare economic cost is the reduced value of DAM exchange, and the benefit is the reduction in the total cost of balancing. CZC not used for DAM exchange can always be made available for exchange of balancing services. Hence, the benefit of reservation is the additional reduction in balancing costs. As CZC for exchange of balancing services in the opposite direction of DAM exchange is free, the additional value is associated with the increased ability to exchange balancing services in the same direction as DAM flows.

As both the value of DAM energy exchange and exchange of balancing services vary from hour to hour, the optimal reservation varies hourly as well. Estimates of benefits indicate that the value of CZC reservation may be significantly reduced, and in some cases reversed, if reservation of CZC is made for cruder time resolutions, or according to a fixed rule as opposed to an optimisation process.

Efficient reservation may be achieved based on DAM and balancing capacity bids. The ideal solution may then be obtained through a co-optimizing algorithm which solves the DAM and balancing markets simultaneously. Nevertheless, the value of balancing services must be based on expectations or forecasted values. The values realized in real-time may be higher or lower than expected values. However, simultaneous allocation provides the efficient solution based on the information available at DAM gate closure.

If the uncertainty is large, the CZC allocation solution may be improved by making adjustments in the reserved CZC via trade in the intraday market. As forecasted deviations change as we get closer to real-time, some of the reserved CZC may be offered to the intraday market, or more CZC may be reserved via counter-trading in the intraday market.

Efficient CZC reservation does not have to be limited to one type of balancing product. The reservation algorithm may include, at least in principle, several markets in different timeframes.

Models for allocation of CZC without a co-optimizing algorithm

If a co-optimizing algorithm is not available, the market sequence may affect the efficiency of reservation. Balancing capacity prices depends on the alternative value of the capacity in the DAM, the expected balancing energy revenues and cost differences between provision in DAM and provision of balancing energy. In Germany, balancing capacity is procured before closure of the DAM, whereas in GB, balancing capacity is procured after DAM closure. Hence, in Germany market participants must predict DAM prices and balancing energy prices when submitting balancing capacity bids, whereas in GB, market participants must predict balancing capacity prices when submitting DAM bids. As it is easier to predict DAM prices than the prices of balancing services, the German sequence may be able to bring the market closer to the optimal solution. The analysed models are all based on balancing capacity bids being submitted prior to or at the same time as DAM bids.

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Co-optimisation may also be achieved via an explicit auction for CZC. In this case, the TSOs may submit transmission capacity bids based on actual balancing capacity bids to the explicit transmission capacity auction. These bids compete with market participants' bids for CZC based on expected DAM exchange values (DAM congestion rent). A weakness of this model is that the granularity of reservation is limited by the granularity of the transmission capacity auction, and that reservation may have to be made a long time before real-time operation.

Market-based allocation is another alternative that can be used in the absence of a transmission capacity auction or a co-optimizing algorithm. In this case, the TSOs allocate CZC to the DAM based on actual balancing capacity bids and expected DAM prices. If balancing capacity bids are not available at the time, as is the case in GB, the TSO must predict the demand for CZC from both markets in order to determine the allocation of CZC between the DAM and the balancing market (cf. the economic efficiency model in the NC EB).

The choice of allocation model depends on the market design. Furthermore, the allocation model may affect to what extent the potential value of CZC reservation is likely to be realized. The main determinants are the granularity of reservation and the uncertainty of expected values of exchange in the relevant markets. The value of CZC reservation varies from hour to hour, particularly since the value of DAM exchange varies hourly. The larger the variation, the higher is the efficiency loss if reservation is made for longer time periods. Moreover, the more the value varies, and the more unpredictable it is, e.g. due to intermittent generation, the higher is the efficiency loss of early and crude reservation.

Another relevant design element is the product definitions in the balancing markets. If products are defined differently, the evaluation of reservation is obscured, and so is the possibility to realise the full benefits. Hence, the possibility to reap the benefits of sharing or exchanging balancing capacity may imply a need to harmonise market designs, both when it comes to the product definitions and the market sequence.

Exchange of balancing capacity versus balancing energy

The value of exchange or sharing of balancing services depends on differences in both the cost of balancing capacity and differences in the cost of activation (balancing energy). Balancing capacity is usually procured based on reservation prices only. Ideally, both capacity bids and balancing energy prices should be taken into account, as the total cost of balancing depends on both. However, the providers' balancing capacity bids should reflect the expected revenues from activation, in addition to any changes in costs. Hence, reservation based on balancing capacity bids, if the market is well-functioning, should provide an accurate estimate of the full value of exchange of balancing services, with a measure taken for the unavoidable uncertainty of real-time balancing energy at the time of reservation.

However, if there are interdependencies between bids in the DAM and bids in the balancing capacity market, the allocation may be inefficient if provision is not made for dependent bids, even with co-optimizing with implicit auction. On the other hand, allowing dependent bids may make the algorithm excessively complex, and the potential extra benefit may not be worth the effort. Co-optimisation with explicit auction and the market-based reservation process do not provide for dependent bids.

If TSOs procure balancing capacity separately, i.e. exchange balancing capacity and share balancing energy, the value of reservation is likely to be reduced, although in principle balancing energy will be exchanged according to the same (common) merit order curve.

Other concerns

Some studies point out that the TSOs may have incentives to reserve too much CZC for balancing services, as CZC reservation reduces balancing costs and in addition may increase congestion rents in the DAM. When choosing the model for CZC reservation, regulators should consider the existence of such adverse incentives.

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Moreover, the allocation of social gains (consumers and producers' surplus) may be unevenly distributed between market areas (countries/control areas). For Norway in particular, in situations with a large power surplus, water values may be negatively affected. On the other hand, the balancing capacity prices tend to be high when water values are low, e.g. during summer. The complete picture does however depend on the particular situation, and further studies should be undertaken before a conclusion on the overall effects can be drawn.

Finally, considerations of the value of reservation of CZC should not be based on historical balancing prices for two reasons

- Prices for balancing services may be very sensitive to changes in demand due to CZC reservation, and to changes in the total CZC
- The value of exchange of balancing services and DAM energy is likely to change as the power markets are transformed

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1 INTRODUCTION

1.1 Background and problem statement

Exchange of electricity balancing services (balancing capacity and balancing energy) across borders or zones may increase economic welfare. In order to exchange balancing services, Transmission System Operators (TSOs) must be able to reserve cross-zonal capacity (CZC) to guarantee the exchange of balancing energy during operations. A common European regulatory framework for such CZC reservation is currently developed as part of the Network Code on Electricity Balancing (NC EB). As an example of the relevance of the CZC reservation framework, the Norwegian TSO, Statnett, has requested the opportunity to reserve parts of the capacity on the new interconnectors to Great Britain and Germany for exchange of balancing services.

In order to gain a better understanding of the economic consequences of CZC reservation and receive input on the important factors to consider in regulatory assessments of different reservation methods, the Norwegian Water Resources and Energy Directorate (NVE) has commissioned this report. The main topics of the report are:

- *What are the welfare economic consequences of reservation of interconnector capacity (CZC) for balancing services?*
- *Which elements should the regulator emphasise when evaluating the models for reservation of CZC?*

Reservation of CZC for balancing services implies that the reserved CZC cannot be made available for exchange in day-ahead market (DAM) and intraday markets (IDM). Reducing CZC for DAM trade reduces the congestion revenues on the CZC and may affect (DAM) prices in the interconnected markets. In order for the CZC reservation to enhance the total economic value of the CZC, the expected gain from the balancing market must be higher than the loss in the DAM and IDM. The welfare economic value is optimized when the CZC is allocated so that the marginal value of exchange of balancing services is equal to the marginal value of DAM and IDM trade (marginal value principle).

The assessment of losses and gains depends on the method by which the CZC is allocated between the markets. ENTSO-E's final proposal for the NC EB presents three different methods for CZC reservation for exchange of balancing capacity and sharing of reserves. All of these are based on the marginal value principle for allocation of CZC. This report focusses on two of the proposed models, i.e. the co-optimisation model and the market based reservation model.

1.2 Definitions

Some useful definitions used in this report are

Balancing: All actions and processes through which the TSOs ensure to maintain system frequency in real-time.

Balancing Capacity: Contracted reserve capacity.

Balancing Energy: Energy used by TSOs to perform Balancing.

Balancing Services: Either or both balancing capacity and balancing energy.

Common Merit Order List: Balancing energy bids sorted in order of activation prices, used for the activation of balancing energy bids within a coordinated balancing area.

Coordinated balancing area: Cooperation with respect to the exchange of balancing services, sharing of reserves or operating the imbalance netting process between two or more TSOs.

CZC: Cross-zonal (transmission) capacity.

CZC Reservation: The reservation of CZC for exchange or sharing of balancing services, implying that the reserved CZC is not available for DAM or IDM trade.

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DAM: Day-ahead market.

Exchange of Reserves: A TSO has the possibility to access reserve capacity connected to another control area to fulfil its reserve requirement. These reserves are exclusively for this TSO, meaning that they are not taken into account by any other TSO in their reserve requirement.

IDM: Intraday market.

Reserve capacity: Capacity paid to be available for provision of balancing energy.

Sharing of Reserves: More than one TSO take the same reserve capacity into account to fulfil their respective reserve requirements.

TSO: Transmission System Operator.

1.3 About the report

The report has the following chapters:

- In chapter 2, we describe our general theoretical framework for assessing the economic costs and benefits of CZC reservation.
- In chapter 3, we review some of the research literature on CZC reservation.
- In chapter 4, we discuss different models for exchange of balancing services.
- In chapter 5, we present the results from a model-based analysis of the market impact of CZC reservation and compare with the theoretical insights and results from the literature review.
- In chapter 6, we provide our conclusions on the costs and benefits of CZC reservation and give our recommendations on which elements the regulator should emphasise when evaluating reservation models.

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2 THEORY AND WELFARE ECONOMIC PRINCIPLES

In this chapter, we present our general theoretical framework for assessing the economics of CZC reservation. We start out by describing the basic model assumptions before presenting the analytical framework in more detail.

We focus on the implications from a Norwegian point of view, i.e., the model describes one country with a hydro power based system, and the other interconnected market as a larger market dominated by renewables and conventional thermal capacity.

Please note that the export country can offer down-regulation to the import market, and the import market can offer up-regulation to the export market, without reservation. Hence, only regulation in the same direction as the flow in the DAM requires reservation of CZC. Implicitly, we assume that the flow direction in the DAM is easy to predict, so that reservation in both directions will generally not be applicable.

In this general analysis, we do not consider the impact of technical restrictions such as ramping restrictions. This is a potential area for further study.

As a starting point, we discuss CZC reservation in general terms and do not distinguish between balancing capacity and balancing energy. Cf. the definition used by ENTSO-E: "*Balancing capacity is secured by the TSOs to have access to power capacity for control purposes in their control area, while balancing energy is activated from the balancing capacity (or other available resources) by the TSOs in real time to maintain the balance within their control area (ENTSO-E, 2011)*[1]." However, we return to the distinction between balancing capacity and balancing energy in the later analysis where relevant.

2.1 Optimal allocation of Cross-Zonal Capacity

We define the issue based on a simplified model with two electricity markets, a day-ahead market for electric energy and a market for balancing services. The model has the following elements:

- Two interconnected countries, A and B
- Power demand is fixed in A and B
- Allocation of CZC in the day-ahead market (DAM) via implicit auction
- Balancing capacity is reserved for provision of balancing energy in A and B
- The CZC may be reserved for exchange of balancing services

We study situations where the CZC is fully utilized for DAM exports from B to A without reservation, and analyse the situation where some of the CZC is reserved for up-regulation from B to A.

Based on the simplified market description, we go on to describe the conditions for optimal allocation of CZC, the value of CZC in the different markets, and the market implications.

Reservation of CZC for balancing services implies that less CZC is available for DAM exchange. The allocation between the DAM exchange and exchange of balancing services is optimal when the marginal value of the CZC is equal in the two markets.

Figure 2.1 illustrates the optimality principle. The line sloping upwards from left to right, illustrates the marginal value of DAM exchange on the CZC, or the demand curve for CZC from the DAM. We measure exports from B to A from right to left in the figure. In this case, the CZC would be fully utilized for DAM exports from country B to country A without reservation of CZC for exchange of balancing services (since the value is positive for the whole range of the CZC).

[1] ENTSO-E, 2011. Position Paper on Cross Border Balancing. Working Group Ancillary Services. "Reserve capacity" is replaced by "Balancing capacity" in the quote, to keep the terminology in accordance with the definitions in NC EB.

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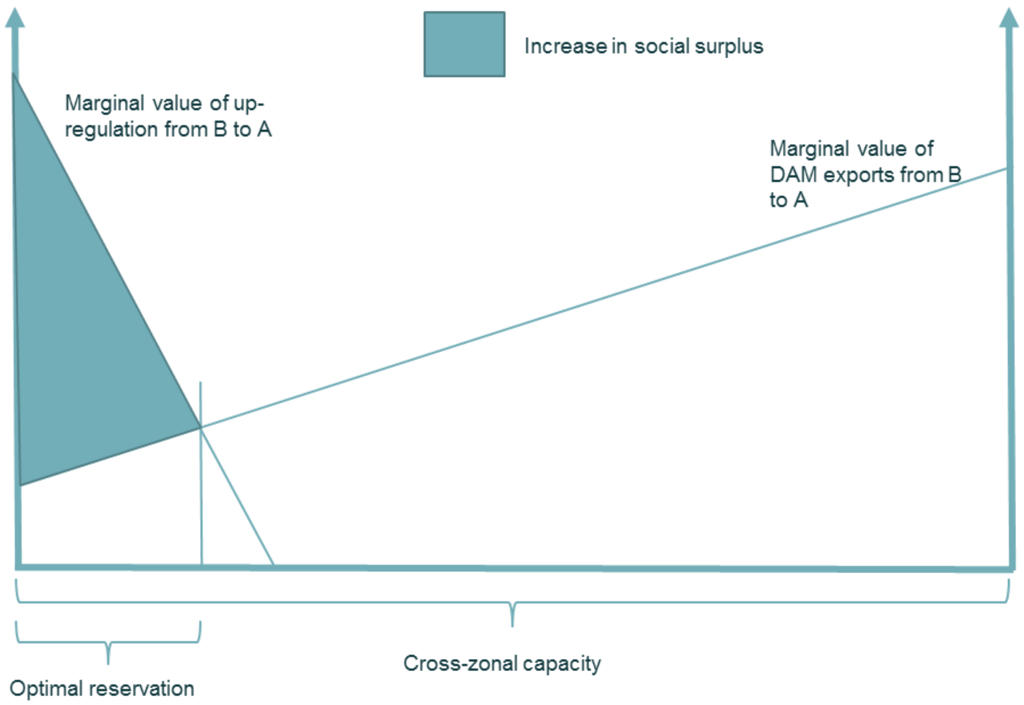
In order for CZC reservation for exchange of balancing services to be beneficial, the value of exporting up-regulation from B to A must be higher than the value of DAM exports. The line sloping downwards from left to right in the figure represents the value of CZC reservation for up-regulation from B to A, i.e. the demand curve for CZC from the balancing market. The optimal allocation of the CZC is found where the marginal value of DAM exchange and reservation for exchange of balancing services is equal.

Where the two lines intersect, the total value of the CZC is maximized. This is the optimisation principle laid down in the NC EB as well. The blue triangle represents the increase in social surplus associated with reservation of CZC for balancing services, compared with the situation where the capacity is fully utilized for DAM exchange.

Figure 2.1 Optimal allocation of CZC capacity between trade in DAM and balancing services



As market prices and the value of balancing services vary from hour to hour, the optimal allocation of the CZC capacity varies as well. Ideally, reservation of CZC should be made hourly and only to the extent that the benefits of utilizing balancing services in A in that hour is higher than the value of DAM exchange in that hour.

Hence, in order to determine the optimal allocation of the CZC between DAM exchange and exchange of balancing services, we need to determine the value of exchange in the two markets, or the demand for CZC from the two markets.

2.2 The value of DAM exchange

Reservation of CZC for balancing services affects the DAM as illustrated in the figure below. In the hour illustrated in the figure, the marginal generation cost is clearly higher in country A than in country B. Hence, if the CZC is fully utilized for DAM exchange, country B will export 1400 MW to country A. The DAM trade reduces the overall generation costs by increasing generation in country B – which has the relatively cheaper generation capacity – with generation in country A – which has the relatively more expensive generation capacity. The resulting DAM price in country A is Pa1 and the DAM price in country B is Pb1.

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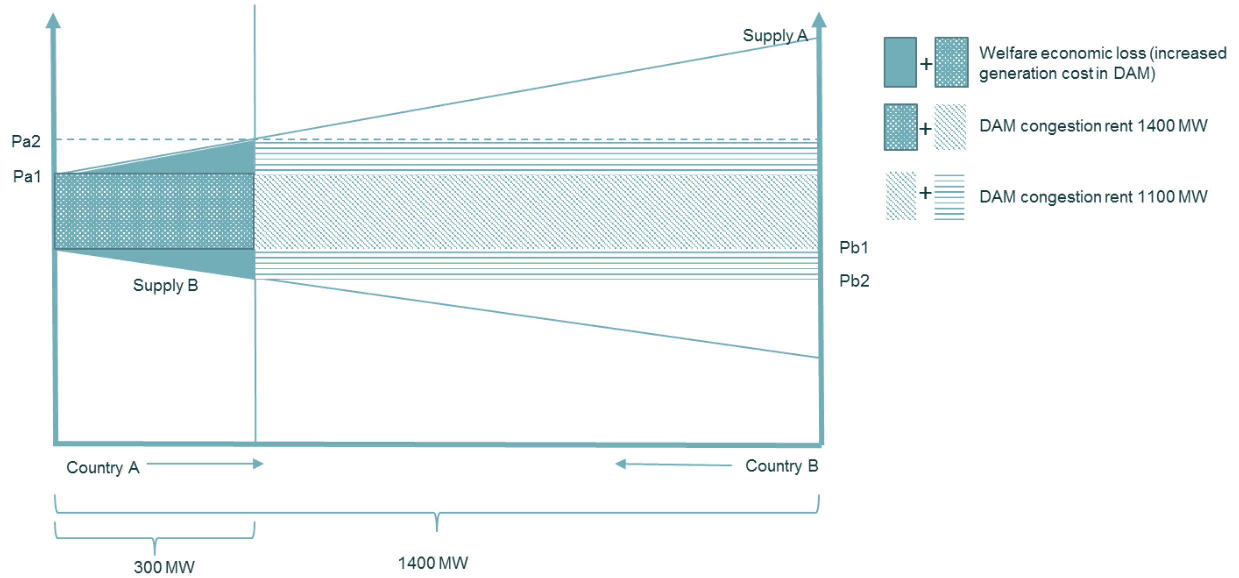
Price effects

If, say, 300 MW of the CZC is reserved for exchange of balancing services, the flow from B to A is reduced to 1100 MW in the relevant hour. This means that generation in A has to increase by 300 MW and generation in B has to decrease by the same volume. The price in A increases to Pa2 and the price in B decreases to Pb2. The total loss in social surplus is equal to the increase in total generation costs, i.e. the blue triangle in the figure.

As the price in B goes down, generators experience a loss while consumers benefit. The distribution effects in A are opposite; generators benefit from higher prices while consumers experience a loss.

The price effects clearly depend on the slope of the curves. If the supply curves around the load levels in the given hour are flat, the price effects may be negligible.

Figure 2.2 Welfare economic impact in DAM from reservation of CZC for balancing services



Congestion rent effects

The congestion rent from the DAM changes as well, as shown in Figure 2.2. Without reservation, the congestion rent is equal to (Pa1-Pb1)x1400 MW, while with reservation it is equal to (Pa2-Pb2)x1100 MW. Since 1400 > 1100 and (Pa2-Pb2) > (Pa1-Pb1) the total effect on the DAM congestion rent depends on the slope of the supply curves and the amount of CZC reservation.

If the supply curves are flat, reservation of CZC for balancing services clearly yields a net loss of social surplus related to DAM exchange. Then market prices do not change (Pa1=Pa2, Pb1=Pb2), and the net loss is equal to (1400-1100)x(Pa1-Pb1).

If country B has exports on CZC to other bidding zones (not in A and B), the DAM price effects imply that the congestion rent from DAM exchange increases on these, as the price difference increases. (If CZC to other markets is optimally allocated between the DAM and balancing services, the CZC reservation should be increased as the value of DAM exchange increases.)

A note on water value effects

The slope of the supply curves in the interconnected bidding zones affect the distribution of costs and benefits, including the distribution of the congestion rent. Generally, the supply curve in a hydropower system (B) is flatter than the supply curve in a thermal system (A). In that case, the effect of CZC reservation on DAM prices in a given hour is smaller in country B than in country A. Figure 2.3 shows the effects if we assume that the supply curve in B is completely flat.

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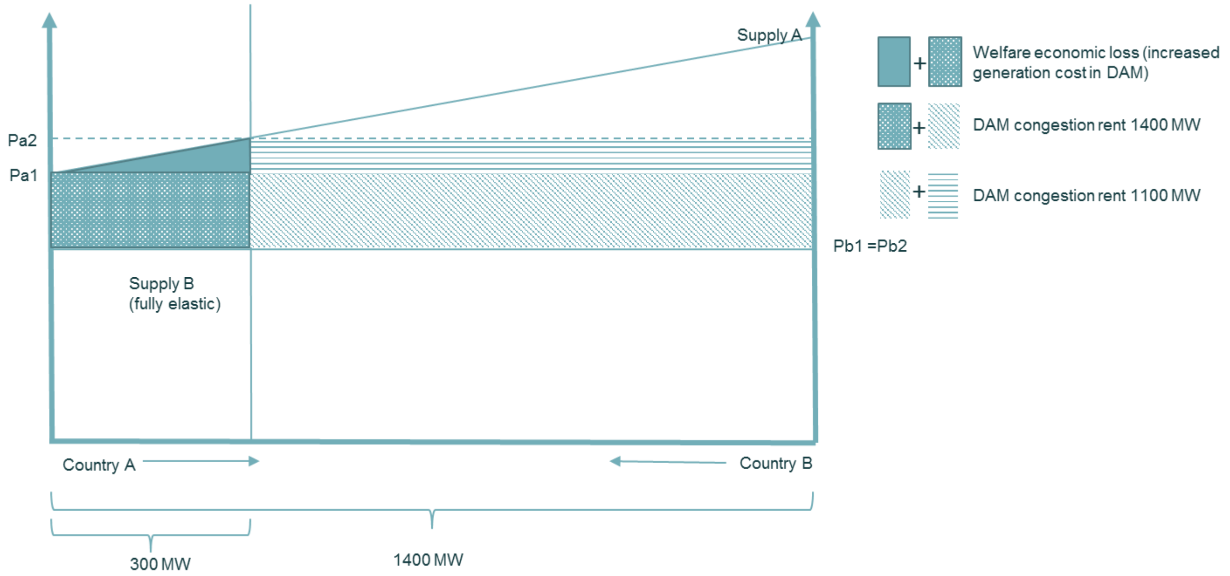
Since generation in B is reduced by the amount reserved for balancing services, water values are affected. Generation capacity reserved for balancing services generally produce (much) less energy than generation capacity used in the DAM. A reduction in the CZC for exports during peak hours does not reduce the total export volume from Norway over time – as annual and seasonal precipitation determine total generation. Reduced energy production due to reduced export capacity means that more water is stored in reservoirs, and is produced in a later hour when prices are lower. In other words, increased CZC reservation for balancing services affects the marginal water values in the hydro system. The implication is that the supply curve is not completely flat even in a highly flexible hydro system. The impact on water values implies that DAM prices in almost all hours are affected by reservation in one hour, whereas reservation in a thermal system only affects DAM prices in that hour.

Figure 2.3 Impact on DAM if the export country is a hydro system



The optimal reservation of CZC for balancing services varies from hour to hour depending on the situation in both markets and both countries. The total effect on water values depends on the shape of the water value curve, the (annual or seasonal) energy surplus and the total reduction in DAM export capacity. We also note that reduced water values due to reservation for balancing services in one hour increases the value of DAM exchange in other hours.

The total impact on water values also depends on the reservation of CZC for up-regulation *from A to B* in hours with DAM imports from A to B. The CZC is fully utilized for DAM imports to B when prices in A are lower than prices in B. If some of the CZC is reserved for exchange of balancing services in these hours, the hydro-power generation will increase in these hours, and the negative impact of reduced CZC for DAM export in other hours is partly counteracted.

Reserving more balancing capacity in the low-cost market for up-regulation, implies that less generation *capacity* is bid into the DAM. Hence, the negative impact on the DAM price level in B may be mitigated to some extent.

From a hydro system perspective, the impact of CZC reservation on the value of DAM trade should take the water value impact into account and not only the price impact in individual hours. Hence, the (marginal) value of DAM exchange cannot be directly inferred from historical market data.

Market agents will take the expected export CZC into account in their DAM bids. If the reservation of CZC is not based on market bids, but on expectations, and the reservation is made for multiple hours, it is important to consider the dynamic water value effects, however.

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2.3 The value of balancing services

To make sure that adequate resources are available for activation on short notice, the TSOs must determine the need for balancing capacity within their control area prior to real-time. Usually, balancing capacity receive a reservation payment and an activation price, if activated. Thus, the total cost is not known a priori.

The reservation price is determined by the TSOs' assessment of the need for reserves, and the suppliers' assessment of the cost of reserving capacity. The suppliers' assessment is again based on expectations of the alternative value of the capacity, i.e. for DAM generation or generation in the IDM, and the expected revenue from provision of balancing energy, in addition to any changes in costs. Hence, the balancing capacity bids reflect the expected value of balancing energy.

While the reservation cost is derived from the bids in the two markets, the activation cost is only known ex post. Hence, the estimated value of exchange or sharing of balancing services will always be uncertain. This does not imply that an optimal exchange volume cannot be found. Rather, an optimal allocation of CZC requires that the inherent uncertainty is taken into account in an efficient manner.

The value of reserving CZC for exchange of balancing services is

- That balancing capacity reserved in one control area may be used for balancing in another control area, thereby reducing the need for reservation of balancing capacity in the high-cost TSO's control area. In addition, as balancing capacity can be shared, the total reservation of balancing capacity may be reduced.
- That reserved balancing capacity in the two control areas can be utilized according to a common merit order within the available CZC, thereby reducing the total cost of balancing energy.

As in the DAM, cf. Figure 2.2, the marginal cost of balancing services is likely to increase in the low-cost country, and decrease in the high-cost country. The cost of balancing, spread across all users of the grid, will thus increase in the low-cost country. However, the producers' surplus will increase as more balancing capacity is reserved, and the marginal balancing capacity price increases. The impact on the balancing energy price should be similar.

Also similarly to the effect in the DAM, a congestion rent should accrue to the CZC, and consist of the difference in balancing capacity prices plus the difference in balancing energy prices when "foreign" resources are activated.

The same power plants provide both DAM energy and balancing energy. In order to be able to provide up-regulation, the unit has to be "spinning", i.e. already in operation. The cost of providing up-regulation (balancing energy) may also vary depending on the level of capacity utilization. Hence, the cost of and ability to offer balancing energy depends on the DAM deliveries. When the DAM price is higher than the water value, the alternative value of the balancing capacity is equal to the lost revenue from the DAM (DAM price minus water value). When the DAM price is lower than the water value, the plant must generate DAM energy in order to be able to deliver up-regulation. Hence, the opportunity cost is the difference between the water value and the DAM price.

2.4 Real-life challenges

Ideally, the allocation of CZC between DAM exchange and exchange of balancing services should be made hourly, and the optimisation should be done based on actual values in the two markets. In reality, this may be difficult to accomplish.

The CZC made available for DAM trade is typically announced by the TSOs prior to market closure in the DAM. Some TSOs also determine the need for balancing capacity prior to DAM closure, whereas others determine the need after gate closure in the DAM.

If balancing capacity bids are collected before closure in the DAM, the demand curve for exchange of balancing capacity may be deducted from the actual market bids. However, in this case, the value

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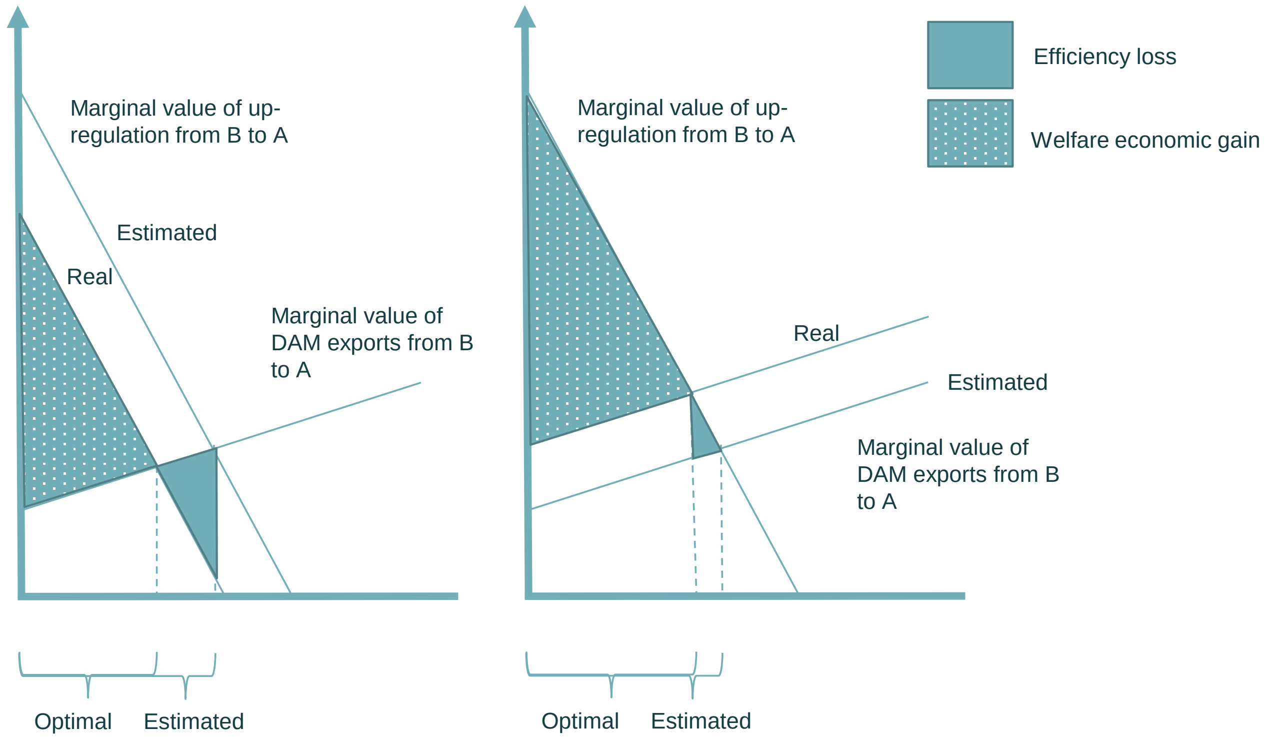
of DAM exchange is not known until after DAM closure, and the allocation of CZC must be based on forecasted DAM values.

If balancing capacity bids are collected after DAM closure, the CZC reservation must be based on expected values of exchange of balancing capacity as well.

If expectations and estimates of the demand curves for CZC in the two markets turn out to be wrong, the allocation of CZC is (ex post) sub-optimal. Sub-optimal allocation of the CZC yields welfare losses as depicted in Figure 2.4. Too low allocation may be the result of wrong expectations about the value of exchange of balancing services, as shown in the left panel, or wrong expectations about the value of DAM exchange, as shown in the right panel.

Figure 2.4 Welfare economic loss due to sub-optimal allocation of cross-zonal capacity



In the case depicted in the left panel, the value of balancing capacity is over-estimated. Then, a part of the CZC is used for exchange of balancing capacity although the value of DAM exchange is higher. The efficiency loss is equal to the blue triangle in the figure. In the case depicted in the right panel, reservation is too low because the value of DAM exchange is underestimated. Similar welfare losses accrue if too little CZC is reserved for balancing. In both cases, there is still a net benefit of reserving CZC for balancing, as illustrated by the shaded blue triangles. However, the more erroneous the estimated values, the greater is the risk that the efficiency losses outweigh the welfare economic gain of CZC reservation.

The value of power exchange in the DAM and the value of exchange of balancing services change from hour to hour. Optimal allocation of CZC requires that the reservation can be changed from hour to hour. If reservation is not made on an hourly basis, but for cruder time resolutions, e.g. load blocks, weeks, months, seasons or years, the allocation will also not be optimal for most hours. The welfare loss is likely to be higher the cruder the time resolution of the reservation, and the larger the variation in market values.

The magnitude of errors related to forecasted values depends on

- The slope of the demand curves in both markets
- The uncertainty of demand curves in both markets

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- The magnitude of potential erroneous expectations in both markets

As we can see from the figures, the slope of the "demand" for CZC for the two purposes affects the potential value loss. If we expect the demand for balancing services to be steeper than the demand for DAM exchange, erroneous expectations about DAM prices may yield higher welfare losses than erroneous expectations about the value of exchange of balancing services.

The more uncertain the demand curves are, the more often one may expect the reservation to be inefficient. Moreover, it matters "how wrong" expectations are likely to be.

An example: With increasing shares of intermittent renewable generation capacity in the systems, it is all the more likely that expectations will be wrong, and the magnitude of errors is likely to increase. At the same time, the need for balancing capacity is set to increase when the share of intermittent generation in the system increases. Hence, it becomes more important to reduce forecasting errors and to make reservation on a finer time resolution basis.

Another possible practical challenge is the definition of the balancing products in the two interconnected markets. Without similar product definitions, there is a greater risk of inefficient exchange of balancing services, even if the market design is otherwise efficient.

Finally, the generators may face practical challenges when making their bids. If the market design is based on a simultaneous allocation of CZC between the DAM and balancing services, the cost of providing balancing services will depend on the outcome of the DAM clearing. For instance, a generator cannot offer down-regulation unless his bid in the DAM has been accepted. Similarly, a generator cannot at the same time sell balancing services and energy in the DAM in excess of the installed capacity. An efficient bid strategy may then involve making bids that are mutually dependent. With many balancing products, the market-clearing algorithms and generator bidding strategies may be highly complex if such dependencies are to be taken into account.

2.5 Summary of chapter

Optimal CZC allocation requires that both markets, i.e. the market for balancing services and the DAM, be solved simultaneously, based on market bids in the DAM and in the balancing market. Moreover, as the value of CZC in both markets vary from hour to hour, the optimal allocation of CZC varies from hour to hour as well.

If the allocation is based on estimated (forecasted) values (bids), the allocation is likely to be sub-optimal, and the full efficiency potential is not likely to be realized. If expectations are very different from the actual market values, the efficiency loss may be greater than the welfare gain of reservation. The risk of efficiency losses increase if

- a small error in estimates has a large impact on the reserved CZC, which is more likely if the value of exchange of balancing services is over-estimated and the value of DAM exchange underestimated, and the slope of the demand curves are fairly flat;
- the uncertainty is high, e.g. because of intermittent generation or estimates have to be made a long time before real-time; or
- the magnitude of potential errors is large, i.e., the shares of intermittent generation are large.

As the optimal allocation of CZC is likely to vary from hour to hour, reservation of fixed amounts for longer periods will reduce the efficiency gain of reservation. A combination of crude time resolution for reservation and large variations in values increases the risk of completely eroding the welfare economic gains of reservation.

Here we have only studied the value of up-regulation from the low-cost country. However, it should be noted that CZC reserved for up-regulation in the import country could also be used for down-regulation in the export country. This may represent an additional value if down-regulation is cheaper in the import country, not taken into account in the simplified analysis above.

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3 INSIGHTS FROM THE LITERATURE

In this chapter, we review some of the recent academic literature and relevant consultancy reports on CZC reservation. We start out by describing the individual studies before summarising and comparing insights at the end of the chapter.

3.1 Badano et.al.

Badano et.al. (2014) have calculated the value of reserving 100 MW of capacity between Sweden and Germany (SE4-DE) during 2012. The DAM cost is found to be approximately 40 mill. €, while the reduction in German balancing costs is approximately 80 mill. €.

The estimate is based on historical data. The impact on DAM prices is not taken into account, which implies that "these figures are too optimistic in terms of cost savings". In order to assess the costs and savings based on historical data properly, the bid curves for all regions and both markets should be available.

3.2 Doorman and van der Veen

Doorman and van der Veen (2013) analyse different designs of cross-border balancing, and argue that designs with a common merit order list (MOL) is likely to yield the most efficient solutions. The market designs may be distinguished along several characteristics, but the analysis focuses on the organization of exchange of balancing capacity and balancing energy. "*Balancing capacity is secured by the TSOs to have access to power capacity for control purposes in their control area, while balancing energy is activated from the balancing capacity (or other available resources) by the TSOs in real time to maintain the balance within their control area (ENTSO-E, 2011)*[2]*.*"

Both balancing capacity and balancing energy can be exchanged in different manners:

- By imbalance netting, implying that "opposite" imbalances are netted across control areas, reducing the cost of balancing for TSOs. By definition, imbalance netting only involves exchange of balancing energy.
- By BSP-TSO trading, implying that the BSP (Balancing Service Provider) can choose which TSO to supply balancing services to, i.e., cooperating TSOs allow direct exchange of balancing capacity and balancing energy into the other TSO's control area. BSP-TSO trading may be combined with an additional voluntary pool where the cooperating TSOs create a common market place, by which they share some or all of their balancing energy bids.
- Through a common MOL, implying that the TSOs pool the bids from their BSPs. A common MOL can be established for balancing energy only, or for both balancing capacity and balancing energy. A common MOL usually includes imbalance netting.

Doorman and van der Veen (2013) evaluate the market designs using a set of criteria involving:

- Allocative efficiency, i.e. optimality in the use of balancing services
- Price efficiency, i.e. cost-reflectivity of prices
- Price volatility
- Efficiency of cross-border capacity (CBC) allocation, i.e. that CBC is only reserved for system balancing if such reservation enhances social welfare
- Dynamic efficiency, i.e. incentives to increase system security in the long run
- Minimum reserve requirement, i.e. optimisation of balancing capacity requirements
- Non-discrimination, i.e. fair treatment of all market participants

They conclude that the common MOL solution is preferable because designs with BSP-TSO trading are likely to reduce the effectiveness of the balancing energy and balancing capacity markets, the balancing planning accuracy, and the price efficiency. They also point out that a common MOL for balancing capacity does not increase merit order efficiency compared to a common MOL for

[2] ENTSO-E, 2011. Position Paper on Cross Border Balancing. Working Group Ancillary Services.

balancing energy only. A common MOL for balancing capacity may reduce the total need for balancing capacity (if the cooperating TSOs take the access to cross-border balancing services into account when assessing their reserve requirement), and, hence, the cost of balancing. However, the activation of balancing energy is likely to follow the same merit order even if TSOs procure balancing capacity separately and then establishes a common MOL for balancing energy. The procured balancing capacities will be efficiently utilized through the common MOL for balancing energy in both cases.

Although reservation of CBC with common MOLs increases the effectiveness and price efficiency of the balancing capacity market, such reservation may reduce the efficiency of CBC allocation. This claim is not further substantiated in the paper.

3.3 Frontier Economics

3.3.1 Frontier (2009)

Frontier (2009) discuss whether reservation of CZC for exchange of balancing services could enhance economic welfare. They argue that, as demand for balancing energy and demand for day-ahead energy derive from different needs, there will be a difference in social welfare arising from the use of capacity for day-ahead trade and balancing exchange. Thus, it is highly unlikely that the optimal solution is always to allocate 100% of CZC capacity to day-ahead trade. A prohibition on reservation of capacity from the DAM could reduce social welfare substantially.

In addition, optimal allocation of CZC should encourage more efficient investment in sources of flexible generation, and also in CZC itself.

They also note that other market design aspects may affect the social welfare implications of capacity allocation:

- Use it or lose it arrangements make longer-term trade in balancing products difficult
- In markets with explicit auctions for CZC, TSOs and participants may be able to purchase capacity in the DAM market and use it for balancing exchange (subject to local regulations).
- In markets with implicit auction markets, it is more difficult for either TSOs or participants to purchase CZC capacity and use it for balancing exchange.

They do however point out that arrangements could be made to facilitate balancing exchange. Possibilities include changing the market coupling algorithm “to optimise bids for pure capacity alongside capacity and energy”, or by TSOs using counter-trade to free up CZC for balancing trade after the DAM solution. Complexity, transactions costs and property right issues must however be taken into account. The alternatives are not further elaborated in this rather early report.

3.3.2 Frontier (2013)

Frontier (2013) points out that countries apply different order of markets that determine DAM and balancing prices

- Germany: auctions for balancing capacity, setting the price for reserve energy[3], take place before closure of the DAM
- GB: balancing mechanism closes after the DAM (after all *ex ante* trading has concluded)

They propose that the German sequence may be preferable as DAM prices are easier to forecast than balancing prices. Moreover, they argue that the IDM may provide TSOs with an opportunity for countertrading in order to improve the efficiency of the capacity allocation. For example, after gate

[3] Balancing capacity providers are selected according to capacity prices only. The activation price is only taken into account if, on the margin, two bids are equal (capacity prices). Subsequent activation is made according to the energy prices (activation price merit order).

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closure the TSOs may find that the DAM market solution or market developments – e.g. changes in wind power forecasts – imply that optimal reservation is higher than estimated. Then more CZC can be "reserved" by the TSOs buying generation in the import market and selling generation in the export market through the IDM. They do however warn that the lack of depth in the IDM may yield inefficient outcomes, compared to the solution that would have resulted had the reservation been made prior to DAM closure.

In a generalized model of CZC reservation they find that

- Reservation yields a benefit in a large number of situations
- The payoff is higher when balancing prices are expected to be volatile
- The value of reservation is lower when the value of DAM exchange is high

The study estimates that there is a benefit to reserving capacity for exchange of balancing services between France, Germany and GB in about 50-60 % of the hours and that the value is on average 30 €/MW/hour. They find that the value of reservation is generally high as there is a small DAM price difference between the markets. As supply curves are relatively flat, they do not estimate that reservation will have a substantial impact on DAM prices. The difference in DAM prices, and hence the value of DAM exchange, is however higher in peak hours.

This study also points to some possible problems related to the TSOs incentives. Essentially, they argue that capacity reservation is "free" for TSOs, implying that they will be tempted to reserve too much capacity for exchange of balancing services. The reason is that the TSOs do not bear the full cost of reduced DAM exchange. The issue of CZC reservation is compared with a situation where the congestion occurs within a bidding zone. Then, in theory, the TSO could counter-trade in the DAM to free CZC for exchange of balancing services. Thus, the TSO would face the correct trade-off between the markets (cost of reducing trade in DAM vs. benefit of lowering the cost of procuring balancing services. With reservation of CZC, the TSO is not similarly exposed to the DAM cost, as the congestion rent may actually increase. Thus, it is important that the TSO incentives are not unduly focussed on reducing balancing costs.

3.4 Mott MacDonald and Sweco

The study by Mott MacDonald and Sweco (2013) was made for the European Commission. The study assesses the pros and cons of different arrangements for cross-border exchange of balancing services and quantify the benefits of different models.

The empirical analysis finds significant potential welfare benefits of cross-border trade in balancing energy and sharing of balancing services. Annual benefits are estimated at 51 mill € between France and GB, and at 221 mill € in the Nordic region. Across the EU, integration of balancing markets and sharing of reserves could reduce operational costs by as much as 40%.

The integration of balancing markets may be necessary in order to realize the potential for renewable energy in some areas. Moreover, increased integration of intraday and balancing markets would enhance the value of the transmission network.

The study points to an integrated model with a multilateral TSO-to-TSO platform based on a common MOL as the preferred solution. The implementation of a common MOL does however require harmonization of rules and responsibilities between control areas.

As far as we understand the study, they do not explicitly recommend mechanisms for reservation of CZC . They do however note that experience with the PJM nodal algorithm suggests that it is possible to include the DAM, IDM and real-time markets in the same architecture, and to produce both energy and transmission prices frequently (every 5 minutes).

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3.5 NTNU Discussion Papers

3.5.1 Gebrekiros and Doorman (2014)

Gebrekiros and Doorman (2014) analyse the optimal reservation of CZC on different borders. The optimal reservation is based on balancing capacity bids and expected day-ahead prices. The results show that the share allocated to exchange of reserves differs widely between CZCs, including also the variability in the optimal reservation. While optimal reservation between Norway and the Netherlands is consistently high, the optimal reservation between the Netherlands and Germany is highly volatile. Moreover, reservation may reduce costs in the DAM in the most expensive market, as some of the domestic flexible resources may be used on the DAM that would otherwise be reserved for balancing.

3.5.2 Gebrekiros et.al. (2013)

In a working paper currently under revision, Gebrekiros et.al. (2013) find that the balancing services bidding prices for Frequency Restoration Reserves (FRR) are determined by the difference between the daily averaged spot price forecasts and the units' marginal costs. While the day-ahead costs are positively correlated to system load, total reserve procurement costs are negatively correlated to system load. The results are derived from a model based case study of the North European power system.

The short-run marginal cost of a hydropower station is the water value. When the average spot price is higher than the water value, the unit typically produces at maximum capacity. The cost of providing up-regulation is the loss of producing at lower capacity, but if the water value is high, this loss can be small. When the water value is higher than the average spot price, the unit will typically not run. If it has to operate in order to provide up-regulation, it has to produce at a loss in the DAM, and this loss has to be compensated in the balancing market.

As could be expected, costs are reduced in the FRR market when transmission capacity is reserved for this purpose.

3.5.3 Jaehnert and Doorman (2014)

Jaehnert and Doorman (2014) analyse the market and distributional effects of reservation of CZC for exchange of balancing services. Three cases are investigated, in which 1) only CZC not utilized in for DAM exchange is used for exchange of balancing services, 2) 5% of CZC is reserved, and 3) 10% is reserved. In the cases with reservation, the reservation is fixed for an entire year.

As expected, CZC reservation reduces the social surplus in the DAM. Moreover, the overall social welfare is reduced, i.e. the benefits of reservation do not compensate the loss in the DAM. Generally, reservation reduces DAM prices in the Nordic area and increases DAM prices in the Continental markets. Hence, Nordic generators incur a loss, while Nordic consumers benefit. TSOs do however benefit from CZC reservation as the balancing costs are significantly reduced. At the same time, the net effect on DAM congestion rents is positive.

The analysis shows that it is beneficial from a pure TSO perspective to reserve more CZC for exchange of balancing services than what is efficient from an overall welfare economic point of view. Moreover, the distribution of social welfare gains may be skewed in favour of the continental market.

3.6 Pöyry

Pöyry (2014) argue that the new market designs will continue to undervalue flexibility, and do not facilitate cross-border exchange of flexibility.

In order to improve the market value of flexibility, they propose introduction of “energy options” and the following steps:

- Imbalance should not be sheltered

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  - All market participants should be balance responsible; and
  - Imbalance prices should reflect the full long-run marginal cost of balancing the system, including reserve costs (procurement of balancing capacity)
- Market designs should support trading of energy options between market participants (including as insurance against imbalance)
- Market coupling should allocate CZC across timeframes based on market values and not a priori reservations, and should provide a way of pricing intraday capacity
- Balancing services should be defined in ways which promote innovation and avoid forcing all providers to predefined characteristics

Hence, when it comes to the allocation of CZC between different markets, they argue in favour of models that base the allocation on market values, including also balancing services with different characteristics.

Any allocation between timeframes that is fixed in advance is likely to be suboptimal. They propose two possible mechanisms to allocate CZC without reservation:

- Implicit energy options market coupling, in which the market coupling algorithm includes the value of cross-border options trade. Here, the energy options are supposed to reveal the value of CZC across different timeframes. This is the ideal solution.
- Allow energy options trading supported by explicit transmission rights for optional use intraday, i.e., participants in the DAM and IDM bid for transmission rights for later use. The benefit of this solution is faster implementation.

Both approaches implies that the value of CZC is realized in the DAM algorithm.

3.7 Summary of chapter

The literature clearly demonstrates that optimal allocation of CZC has the potential of significantly increasing the social benefit of CZC and reducing the operational costs of TSOs.

However, the results also show that inaccurate ex ante reservation of CZC may reduce the value of reservation substantially. To the extent that values must be forecasted, reservation based on real balancing bids and forecasted DAM prices are likely to be more efficient as DAM prices are easier to predict.

The optimal allocation implies that the allocation is integrated in the day-ahead algorithm. Preferably, the allocation should be adjusted up to real-time if possible. Maximizing the value of CZC requires allocation of CZC across different timeframes, including intraday markets and different balancing "products".

The literature also suggest that mere integration of balancing markets would provide a share of the potential value:

- Cost reductions may be realized by TSOs exchanging balancing energy based on a common merit order list within the available CZC, including "netting" of imbalances.
- Further cost reductions may be realized by TSOs sharing balancing capacity explicitly, enabling TSOs to reserve less total balancing capacity.

Realizing the value of exchange of balancing services, is however likely to require further harmonization of balancing responsibilities and products across control areas.

The distribution of costs and benefits between producers and consumers is not extensively studied, although results indicate that the distribution may be unequal between control areas. Specifically, the case study of Jaehnert and Doorman (2014) indicates that the social cost may be higher in the Nordic countries.

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Some results indicate that the TSOs may have incentives to reserve too much CZC for balancing capacity. The reason is that reservation, in addition to reducing balancing costs, may not have a negative impact on congestion revenues in the DAM. Hence, from an overall welfare economic point of view, it is important that TSO incentives are linked to the impact on social welfare and not limited to the impact on TSO revenues.

The issue of mutually dependent generator bids is not discussed in the literature we have reviewed.

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4 MODELS FOR EXCHANGE OF BALANCING SERVICES

In this chapter, we use the theoretical framework from chapter 2 and the results from the literature review to analyse different types of models for exchange of balancing services. We start out by describing the current Nordic model before concentrating on the two main models suggested in the NC EB.

4.1 Current Nordic model

The current Nordic model has the following main design elements:

1. Allocation and flows in the DAM are determined by the Nord Pool Spot market algorithm. Zonal prices and congestion rents are determined. (12-36 hours ahead of real-time.)
2. Capacity not used by the DAM is made available for the IDM. Intraday trades may always be made in the opposite direction of the DAM flow. Continuous trade as long as the CZC is not congested. No congestion rent accrues to the CZC owners. (The NC CACM foresees that TSOs may develop a pricing method for usage of CZC during the intraday framework.)
3. After gate-closure of the last cross-border market timeframe (intraday), the CZC becomes available for balancing purposes (according to NC EB). Balancing capacity in different bidding zones are shared to the extent that there is CZC available for exchange of balancing energy. In general, different types of balancing capacity are procured nationally, but may be shared according to CZC availability.

The Norwegian TSO, Statnett, procures balancing capacity in different timeframes. For instance, there are day-ahead and week-ahead markets for FCR (the week-ahead only applies to FCR-N for normal operating situations), while FRR-A capacity is procured through a weekly auction. FRR-M capacity is procured through a seasonal and weekly options market ("RKOM"), while the FRR-M balancing energy market closes 45 minutes prior to the operation hour.

4.2 Different models for reservation of CZC

The basic principle for all of the reservation models suggested in the NC EB is the one depicted in chapter 2, i.e. the models build on the principle of equal marginal value of DAM and balancing services exchange. The models deviate in the methods by which the marginal value is determined, i.e. how, when and by whom.

In all models, the TSOs in both markets determine the volume of balancing capacity to be procured for up- and down-regulation in their control area in a given hour (reserve requirement), based on expected needs. Balancing capacity bids may be collected prior to or after gate closure in the DAM. The TSO procurement procedure and whether capacity allocation for DAM trade on CZC are based on implicit or explicit capacity auction, affects the choice of reservation model.

Thus, ENTSO-E proposes three models for reservation in the NC EB:

1. *The co-optimisation process*, in which reservation is based on actual balancing capacity bids and actual DAM bids or DAM prices forecasted by market participants
2. *The market-based model*, in which reservation is based on actual balancing capacity bids and DAM prices forecasted by TSOs
3. *Economic efficiency analysis*, in which reservation is based on balancing capacity and DAM prices forecasted by the TSOs.

Ideally, the hourly CZC reservation should be based on real bids in the DAM and for balancing capacity (at gate closure in the DAM), in a simultaneous optimisation algorithm. If this is not possible, the reservation of CZC must be determined before the actual market bids in the DAM are submitted. As the DAM is a forward market, be it with a short time horizon, the DAM solution is in any case an expression of the market's expectations for hourly trade the next day.

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In markets where balancing capacity is procured prior to gate closure in the DAM, CZC reservation may be based on actual balancing prices. However, in cases where balancing capacity is procured after gate closure in DAM, as in GB, both prices have to be forecasted in order to arrive at the CZC reservation solution.

The approach makes an explicit distinction between balancing capacity and balancing energy, cf. the definitions in chapter 2 (ENTSO-E, 2011). For all models however, the detailed implementation is still to be developed and approved.

4.2.1 Co-optimisation process

In the co-optimisation process, CZC is allocated simultaneously between the DAM and the balancing markets. According to the NC EB version 3.0, this can be done either through an explicit or an implicit CZC auction.

In an *explicit auction*, the TSOs participate in an ordinary transmission capacity auction simultaneously with the procurement of balancing capacity:

1. Both TSOs collect balancing capacity offers in their control area
2. The TSOs bid for transmission rights based on the price difference for different capacity levels in the balancing markets
3. DAM participants bid for transmission rights based on expected price differences in the DAM
4. TSOs win capacity for bids that are higher than the bids from DAM participants

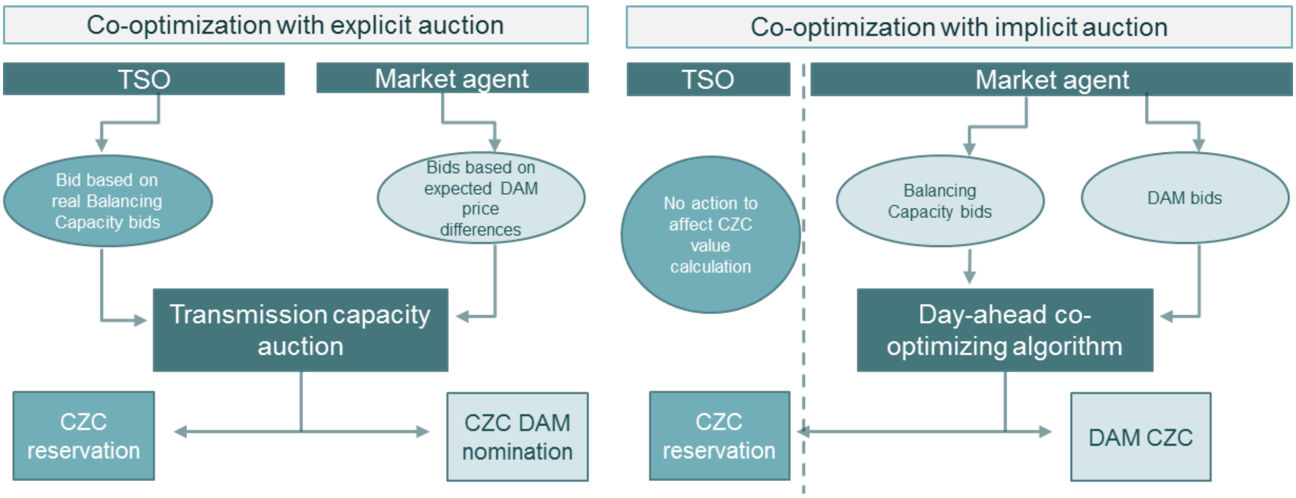
The TSOs must reserve the allocated CZC for up- or down-regulation exclusively, and the reserved capacity is not exposed to use-it-or-lose-it (UIOLI) or use-it-or-sell-it (UIOSI) provisions, as the CZC for exchange of balancing energy has to be available in real-time.

This approach may be stepwise, depending on the design of the transmission capacity auctions. E.g., CZC can be reserved for a year, a month or a week. If the granularity of the transmission capacity auction is crude, the CZC reservation will also be crude.

In markets in which CZC is allocated on the basis of implicit auction (market coupling or market splitting algorithm), the markets may be cleared simultaneously based on bids and offers in the DAM and balancing capacity markets.

The main elements of the two co-optimisation models are shown in the figure below.

Figure 4.1: Co-optimisation procedures



Source: ENTSO-E

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There are two main differences between explicit and implicit auction co-optimisation:

- Basis for value assessment: In the explicit auction co-optimisation, the DAM value is not based on real bids, but on the value expected by market agents, whereas in the implicit auction co-optimisation, the allocation is based on real bids both in the DAM and in the balancing capacity market.
- Timing: In the explicit auction co-optimisation, bids are submitted prior to the DAM market opens, and, depending on the design of the transmission capacity auction, this may be a long time before real-time, whereas in the implicit auction co-optimisation, bids are submitted up to gate closure in the DAM, i.e. much closer to real-time.

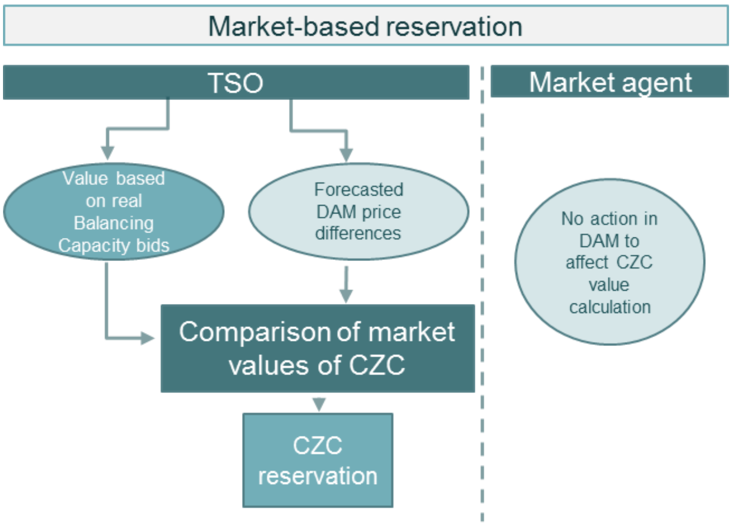
According to Frontier (2013), the co-optimising process with implicit auction removes the sequential process by including balancing bids in the DAM algorithm. Such approaches have been used in markets with centralized dispatch; Australia, New Zealand, Ontario.

4.2.2 Market-based reservation

Market-based reservation is an alternative to explicit auction co-optimisation, i.e. if no transmission capacity auction is available for *the relevant timeframe for procurement of Balancing Capacity*. As the explicit auction co-optimisation process relies on the existence of transmission capacity auctions, the granularity will also be limited by the granularity of these auctions. The market-based model implies that reservation is made by the TSO based on expected price differences in DAM and the actual value of exchange of balancing services, i.e. based on real bids for balancing capacity.

The market-based reservation model is illustrated in the figure below.

Figure 4.2: Market-based reservation



Source: ENTSO-E

According to NC EB, the market-based reservation model may allow the TSOs to make reservations with a finer granularity than in the explicit auction co-optimisation process. The reservation is made by comparing the actual value of exchange of balancing services with a forecasted value of energy exchange. I.e., in this case the value of DAM exchange is based on the TSOs' expectations and not on the expectations of market agents as in the explicit auction co-optimisation model.

In October 2014, Statnett and Svenska Kraftnät launched a pilot project to exchange balancing capacity (FRR-A) through reservation of CZC between Sweden and Norway, the Hasle pilot. This pilot implements the market based reservation model. According to the licence application to NVE, Statnett and SVK will reserve CZC for one week at the time (limited to 5% of planned ATC). The CZC reservation is based on FRR-A capacity bids in Norway and Sweden and forecasted DAM

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prices in the relevant bidding zones. The default forecast for (hourly) day-ahead prices is last week's hourly prices.

4.3 Economic properties of the suggested models

Based on the description of the models suggested in the NC EB and the analysis in previous chapters, we can now assess the economic properties of the two main models.

First, note that all models imply that the value of CZC in the balancing services market is based on real market bids. However, the timing may be different, and the longer in advance of DAM gate closure the balancing bids have to be submitted, the more inaccurate is the implied value likely to be. Co-optimisation with implicit auction is likely to yield the best solution, as balancing capacity bids are submitted simultaneously with DAM bids. Co-optimisation with explicit auction, on the other hand, may imply that balancing capacity bids must be submitted very early, depending on the design of the transmission capacity auction. Market based reservation implies that the TSOs must receive bids for balancing capacity prior to opening of DAM trade, in order to be able to announce the CZC available for DAM trade. However, the TSO may chose the relevant lead time in order to optimize the CZC reservation.

Market-based reservation is potentially more vulnerable to strategic forecasting by the TSOs. The incentives and opportunities for strategic forecasting however also depend on the regulation of the TSO.

Co-optimisation by explicit auction is less flexible than market-based reservation with regard to granularity, as the granularity of reservation is linked to the granularity of transmission capacity auctions. This increases the risk of reserving the wrong level of CZC for balancing capacity, and may also lead to power flows in the wrong direction in some hours. This risk is likely to be removed with implicit auctions as the market agents do not need to predict the direction of power flows, thus reducing the risk of inefficient outcomes (cf. the general discussion on explicit vs. implicit auctions in the DAM).

The issue of dependency between bids in the DAM and bids for balancing capacity is not removed with co-optimisation through implicit auctions. With independent bids, the generators must make predictions about energy and balancing prices separately, which creates some of the same inefficiencies as market-based reservation or co-optimisation with explicit auctions. This is handled in different ways in markets that apply co-optimisation of energy and balancing markets. The Ontario System Operator IESO requires that offers for operating reserves are accompanied by an energy bid or offer for an equal or greater number of megawatts (IESO, 2012, and the references therein). In the Australian market, offers and bids for Frequency Control Ancillary Services (FCAS) utilise a "trapezium" where generators are required to indicate the maximum amount of FCAS for a given MW output level with corresponding prices (AEMO, 2010), which creates a linkage between the bids in the different markets. These examples indicate that it is possible to overcome the practical challenges of dependent bids. It is however outside the scope of this report to elaborate the practical experiences and algorithm requirements in detail. This could be a topic for further study. For further details on international experiences, see appendix 1.

In sum, the co-optimisation model with implicit auctions has several advantages compared to the alternatives.

For co-optimisation with explicit auction, the main drawbacks are the granularity and that the DAM value is based on expectations, not real bids. Here the market-based reservation model is more flexible. However, the finer the granularity of the transmission capacity auction procedure, the smaller the potential advantage of the market-based reservation model in this regard.

4.4 Other relevant design characteristics

The proposed models are only developed at a very general level and several detailed design aspects need to be developed. These include inter alia the possibility of adjustments in CZC reservation after

DAM gate closure, harmonization of product definitions, safety margins in the form of a maximum reservation level, etc.

The allocation of CZC capacity needs to be done prior to or as part of the DAM solution, i.e. usually 12-36 hours before real time, regardless of the chosen model. Market developments after gate closure in the DAM, may imply changes in the valuation of DAM exchange vs. exchange of balancing services. Then, the efficiency of the capacity allocation may be increased by the TSOs using counter-trading to free up capacity closer to real-time. Such trading may mitigate forecast errors made when reserving CZC and make it possible to exploit the capacity even more efficiently. For example, if the TSOs have reserved too much CZC, they can buy generation in the export area and sell generation in the import area. This type of market intervention on the part of the TSO can however be vulnerable to strategic behaviour from the TSOs and raises legal and regulatory questions on the TSO role. This is a topic for further study.

Obviously, in all models, establishment of a common MOL for balancing capacity and balancing energy requires the same product definitions in each country. For instance, procurement blocks for FRR-A and other services should be harmonised.

With both models, it is possible to reduce potential costs from wrong reservation levels by including safety margins to account for uncertainty. On the other hand, this reduces the potential efficiency gains from reservation. However, if the reservation has to be made very early and/or at a very crude time resolution, safety margins may be a useful measure to limit the risk of large efficiency losses in DAM if expectations turn out to be very wrong.

We have argued that hourly reservation is the most efficient solution. Most TSOs do however not procure balancing capacity hourly, cf. e.g., the different timeframes for procuring balancing capacity in the Norwegian and Nordic market at present. However, the CZC reservation does not need to follow the timeframes of balancing capacity procurement. Although the value of CZC for exchange of balancing services may be estimated to be largely the same for several hours, e.g. for all peak hours during a week, the value of DAM exchange is likely to change hourly, and hence, the optimal allocation of CZC between the markets.

In the longer term, flow-based market coupling and changes to bidding zones are likely to have consequences for CZC reservation. Flow-based market coupling implies that the CZC made available to the DAM on different cross-zonal transmission links, is calculated based on an integrated algorithm taking into account market bids and physical flows. Hence, instead of submitting ATC values prior to DAM bidding, which take into account physical flows and internal zonal congestions, the ATC values will be a result of the market algorithm. In this case it should also be possible to integrate balancing capacity bids in the joint clearing of DAM and allocation of transmission capacity (cf. Mott MacDonald and SWECO). If balancing capacity bids cannot be integrated in the flow-based algorithm, models for *prior* CZC reservation must probably be revisited.

We conclude that the value of reservation is affected by the choice of CZC reservation model. However, reservation also affects DAM prices, and hence the value of DAM exchange. When calculating the *potential* value of CZC reservation for exchange of balancing capacity, the possible impact on DAM prices from CZC reservation should be taken into account, regardless of the reservation model, particularly if it is desirable to reserve significant amounts of capacity frequently. Any impact on DAM prices is likely reduce the value of CZC reservation (cf. Badano et al., 2014).

A large part of the efficiency gain from exchange of balancing services is likely to stem from a reduced need for total balancing capacity. However, if there is a high risk that the capacity situation will be simultaneously tight in the two interconnected control areas, the gains from sharing of balancing capacity are reduced: The total amount of balancing capacity will be the same, and the benefits only accrue from the exchange of balancing energy. Hence, the gains from CZC reservation may vary significantly from case to case, and depends on the characteristics of the interconnected markets.

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4.5 Summary of chapter

The Network Code on Electricity Balancing sets out three options for reserving CZC for exchanging balancing capacity:

1. *The co-optimisation process*, in which reservation is based on actual balancing prices and DAM prices forecasted by market participants or based on real DAM bids
2. *The market-based model*, in which reservation is based on actual balancing capacity prices and DAM prices forecasted by TSOs
3. *Economic efficiency analysis*, in which reservation is based on balancing capacity and DAM prices forecasted by the TSOs

We have concentrated our discussion on the first two models. The models differ in respect to the time when balancing capacity bids are submitted, and in the basis for evaluation of the value of CZC for DAM exchange. All the proposed models (except the economic efficiency analysis) are based on real balancing capacity bids. The efficiency of co-optimisation may be very different depending on to whether CZC allocation is based on implicit or explicit auction. While co-optimisation with implicit auction is based on real DAM bids, co-optimisation with explicit auction and market-based reservation is based on values forecasted by the TSOs and the market agents, respectively. Compared to co-optimisation with explicit auction, the market-based reservation model is likely to be more flexible with regard to granularity, and as flexible as co-optimisation based on implicit auction.

Generally, the longer in advance the reservation must be determined, the cruder the time resolution of CZC reservation, and the less reservation is based on real bids, the more inefficient is the CZC reservation likely to be.

The earlier the reservation has to be made, the larger is the risk of inefficient CZC allocation. Co-optimisation with implicit auction bases the reservation of CZC on the most up-dated information, in time for the DAM solution to be calculated.

It is also crucial that reservation is made with an hourly time resolution, regardless of the model chosen. Hourly resolution is easier to obtain with market-based reservation and co-optimisation with implicit auction than co-optimisation with explicit auction.

The result may be further improved by allowing counter-trade in the IDM in order to adjust the CZC reservation up to real-time, based on market developments between DAM gate closure and real-time. Allowing dependent bids is also likely to further improve the efficiency of CZC reservation.

A number of design characteristics that may affect the efficiency of the models are however still pending.

5 MODEL BASED ANALYSIS

THEMA has developed a Northwest European power market model that has been extended to include the opportunity to reserve CZC for exchange of balancing services. In this chapter, we present the model framework and the result of a simplified model analysis. Finally, we compare the model results with the conclusions from the previous chapters.

5.1 Model description

We have carried out illustrative model simulations using THEMA's power market model, and with inclusion of a module for optimisation of CZC between the Norwegian and the German market. The modelling implies that both the generation capacity and the CZC are allocated between the balancing and day-ahead markets, i.e. the resources are utilized in the market which yields the highest economic value. The model allows CZC to be used to provide balancing services provided that the reserved CZC can be backed by balancing generation capacities. Provision of balancing services is modelled as spinning reserves for both up- and down-regulation. Figure 5.1 illustrates the applied model framework.

Figure 5.1 Model framework for the integrated DAM and balancing model

	Specifications	Important constraints
DAM	• NW-Europe • Hourly chronological time resolution • Detailed hydro modelling • Detailed thermal modelling	• Start-up costs • Must-run restrictions • Part-load efficiencies • Individual reservoir constraints
Balancing markets	• Block bids Peak/off-peak per week • CZC can be employed	• Up/down balancing • Spinning/non-spinning • Netting

The DAM is modelled with hourly time resolution. Balancing capacities, however, have to be committed for a longer time period (bid blocks). In this respect we follow the German market design, i.e. balancing capacity is reserved for peak and off-peak hours on a weekly basis. The size of block bids is a crucial element in deciding how much CZC should be reserved. The larger the block bids, the larger the opportunity costs of reserving CZC for balancing. The model also takes activation of balancing capacity into account, i.e. balancing energy.

5.2 Model results

The modelling shows that there is a substantial potential for exchange of balancing services between the two markets (cf. Figure 5.2). Two elements are worth noticing:

1. There are large differences in the need for and value of balancing services in peak and off-peak situations.
2. The CZC reserved for balancing services changes from week to week (i.e. with the granularity of the block bids). Whereas reservation is typically high in winter months and weeks, it is lower in the summer. This underlines the importance of block bids in the considerations. If a constant share of CZC had to be reserved for the entire year, the share of reserved CZC would have been lower.

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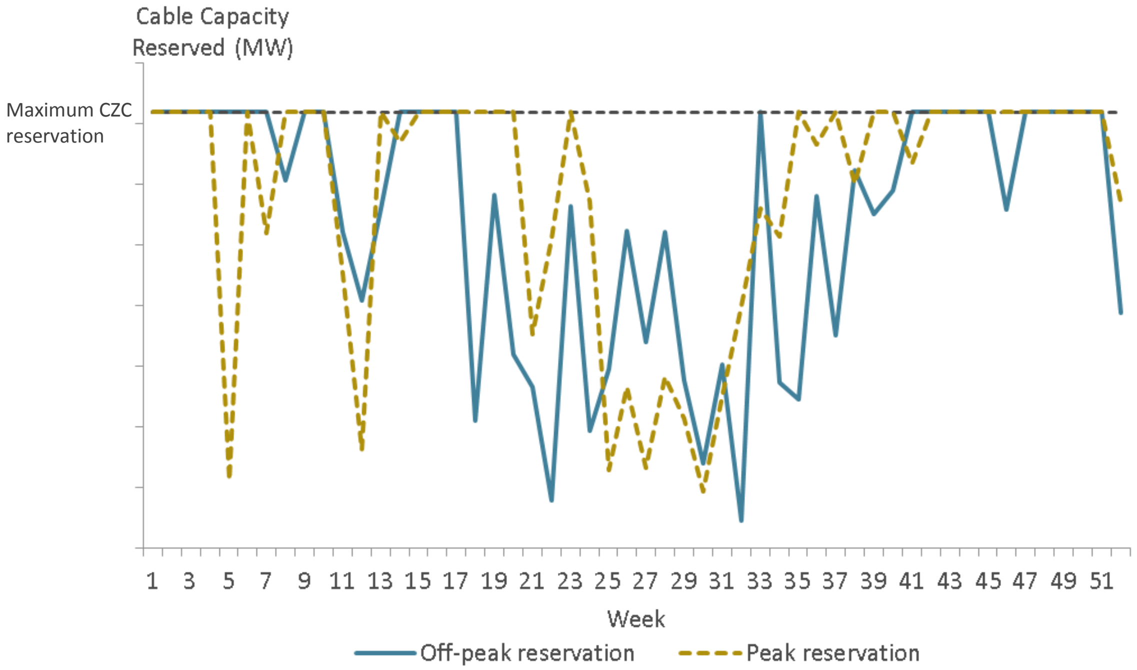
Figure 5.2 Optimal reservation of CZC for up-reserves in Germany



Source: THE-MA model extension with balancing power

Figure 5.2 also indicates a seasonal pattern. More CZC is reserved in winter times than in the summer: The reason for that is twofold. First, the costs of providing balancing services in Norway during summer are high; DAM prices are typically low in summer due to low demand and high shares of un-regulated generation (cf. also Figure 5.3). This increases the opportunity cost of provision of balancing services for hydro power producers. Second, due to low power prices in the summer in Norway, the congestion rent on interconnectors is quite high in these weeks. Thus, the opportunity cost of CZC reservation is high.

One important aspect to take into account is the aspect of “netting”. Netting refers to the fact that that reservation of CZC for up-regulation in one direction provides automatic down-regulation in the opposite direction “for free”. The same holds vice versa. The amount of reserved balancing capacity is determined by the direction with the higher value, but the valuation of the reservation should take into account the additional opportunity for “opposite” regulation.

Increased interconnector capacity – even if only in DAM - will also affect prices for balancing capacity in Norway; in fact the cable may also be employed to provide balancing services in Norway (in addition to what comes for free via “netting”). The effect of the cable on prices for balancing capacity in Norway in off-peak hours is illustrated in Figure 5.3.

The price effect can be split into two elements. First, balancing capacity prices decrease in the presence of the cable, even if the cable is not used to provide balancing services. This is due to the fact that the cable alone, even if only used in the DAM, will impact prices and reserve requirements, and hence the balancing markets (dotted blue line). Second, if the cable is employed for balancing services, the prices for balancing capacity drop even further (yellow line).

Figure 5.3 again shows a clear seasonality. Prices for balancing capacity are high in summer time in off-peak hours. Demand is low, and the share of un-regulated generation is high. In order to be able to provide balancing services, assets with flexibility have to be “online”. But these hydro assets typically have higher water values, which is why their opportunity costs for providing balancing services are high in these weeks.

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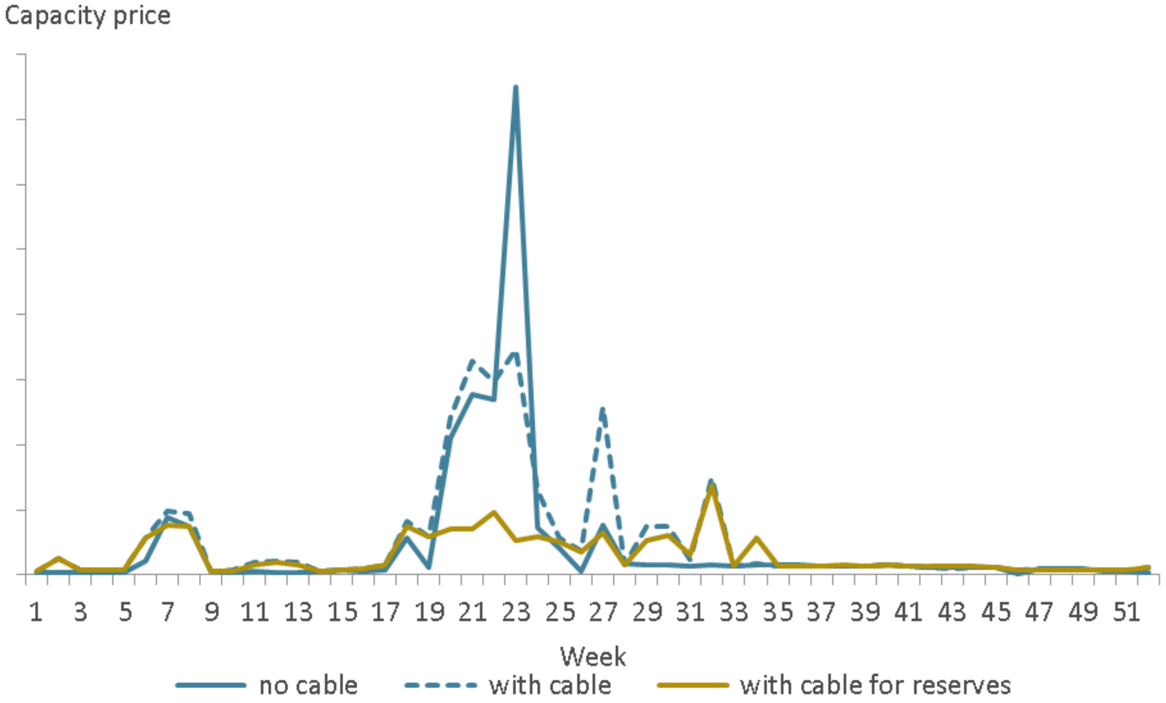
Figure 5.3 Impact of cable on Norwegian prices for balancing capacity for up-reserves in off-peak hours

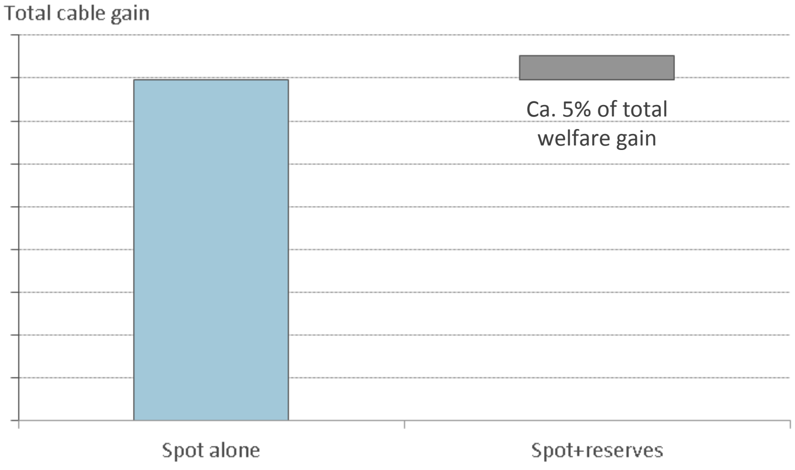


Source: THE-MA model extension with balancing power

We have also studied to which degree the total cable gains derive from DAM benefits and from balancing markets (in case the cable should be employed for exchange of balancing services). The results are summarized in Figure 5.4. We find that the additional gains from providing balancing services are rather modest compared to the gains one may expect in the DAM.

These results of course depend on the assumptions used to model the DAM and balancing markets. But the results display a general guidance rule. If the upside for CZC reservation is low compared to DAM benefits, one should be rather careful in reserving CZC for balancing services. This risk of making an inefficient allocation is always real. Taking this error into account, the extra benefits from balancing markets may not out-weight the loss induced in the DAM.

Figure 5.4 Welfare gains from cable



Source: THE-MA model extension with balancing power

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5.3 Summary of chapter

The model analysis shows that efficiency gains are possible from trading balancing services in addition to DAM energy, although the share of the overall value of CZC from exchange of balancing services depends on the detailed assumptions about the market conditions.

CZC reservation is a possible tool for realising benefits from trade in balancing services. The results indicate that it is sometimes efficient to reserve large shares of CZC for balancing services. Hence, the potential loss from safety margins (caps on reservation) can be significant in some periods (cf. the discussion of safety margins in the previous chapter).

The value of CZC reservation for balancing services varies significantly over the year and with the underlying market conditions. The optimal amount of CZC reservation for balancing services changes from week to week, but is generally higher in winter. This underlines the importance of granularity and uncertainty when considering different models for exchanging balancing services.

Finally, the analysis indicates that CZC reservation will affect balancing prices. This implies that historical balancing prices may not be a good indicator for future prices. Other market changes (apart from new CZC and changes in domestic balancing prices) will also have an impact.

The model analysis is consistent with the results of our theoretical assessments in chapter 2 and the literature review in chapter 3.

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6 CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis in the previous chapter, we may now answer the main questions posed in the introduction:

- *What are the welfare economic consequences of reservation?*
- *Which elements should the regulator emphasize when evaluating models for reservation?*

6.1 Welfare economic consequences

All available studies, including our theoretical analysis and model-based illustrations, show substantial potential efficiency gains of optimal reservation of CZC for exchange of balancing services. Efficiency gains stem from more efficient procurement of balancing capacity (reduced total volume and lower marginal cost), and lower total cost of balancing energy (activation). The producers' surplus is unknown in the absence of information on bid curves in the balancing markets, while the consumers' surplus may be estimated via cost savings for the TSOs (a 40% saving is indicated in the EU study by Mott MacDonald and Sweco, 2013). However, the effects on economic efficiency and wealth distribution may be highly complex due to the interplay between capacity reservation, DAM prices and prices for balancing services.

Real-life challenges imply that reaping the benefits from trade in balancing services is complicated, and that the full theoretical potential is unlikely to be realised. In particular, uncertainty about the value of DAM trade compared to trade in balancing services will have a large impact on the optimal reservation level. Given this, the timing of balancing capacity procurement is a critical factor. Another important factor is the granularity or time resolution of the capacity reservation.

The NC EB proposes several possible models for reservation of CZC for trade in balancing services. The co-optimisation process with implicit auctions is in theory the superior model. This model removes the need for TSOs or market participants to make guesses about prices in the balancing and energy markets. With explicit auctions under co-optimisation or market-based reservation, market agents and/or TSOs must predict prices in the different markets in order to allocate CZC. Hence, co-optimisation with implicit auctions removes some of the fundamental uncertainties with regard to an efficient outcome.

A general challenge with all the proposed models is to make provisions for dependent bids. Generators should ideally be able to specify a linkage between the amount of DAM energy generation and balancing capacity and corresponding prices/marginal costs, which also creates a need for complex algorithms for jointly optimising the energy and balancing markets (particularly with several balancing products). Co-optimisation with implicit auction could however account for dependent bids in the algorithm. Experience from electricity markets elsewhere indicate that it is possible to do this in practice, although the issue needs to be further examined.

CZC reservation needs to be done prior to or as part of the DAM solution, and has to be based on the information and expectations of the real-time situation in the operation hour. As new information accrue between DAM gate closure and real-time operation, the solution may be adjusted by counter-trading in the IDM. In principle, the TSOs may free up CZC for exchange of balancing services through counter-trading, even without CZC reservation as well.

6.2 Elements regulators should emphasize

From a regulatory perspective, our main conclusion is that simple rules for evaluating the value of CZC reservation is not possible. The value of capacity reservations depends on a number of factors and is subject to great uncertainty.

In that regard, the regulator should assess granularity, product definitions, timing of balancing capacity procurement and CZC reservation, price volatility (in the DAM and IDM) and the future generation structure. The more uncertainty about the value of trade in balancing services compared to DAM exchange, the less efficient CZC reservation may be, depending on the chosen model for reservation. As a general guideline, reservation for long periods should be avoided, as it increases the risk of inefficient allocation (given the many factors that influence the value of reservation).

The regulator should also look at the effects on wealth distribution from CZC reservation. Although it is outside the scope of this report to investigate the empirical consequences of CZC reservation, we hypothesise that the distribution effects may be closely linked to the expected direction of trade. For instance, a situation with a large power surplus in Norway and DAM trade predominantly in the direction from Norway, may lead to the bulk of the gains from trade in balancing services accruing to other trading partners depending on the CZC under consideration. This should be addressed through the CZC business model.

Finally, we note that the impact of CZC reservation on balancing prices means that historical prices may not be a good indicator of future prices. However, increased cross-zonal capacity also affects DAM prices, which again affects the value of CZC reservation.

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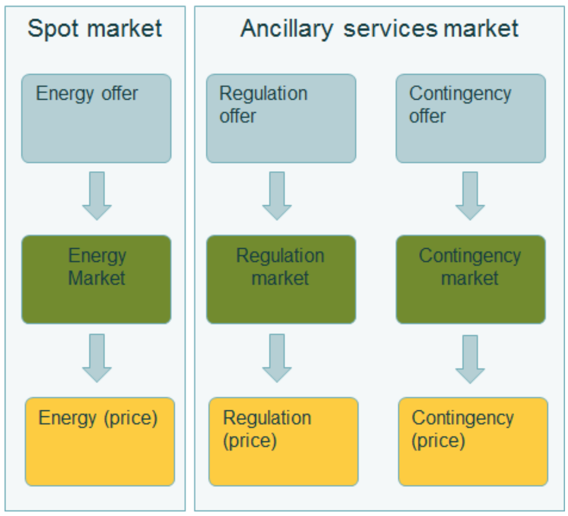
APPENDIX 1: EXISTING CO-OPTIMISATION MODELS

Co-optimisation (also known as joint optimisation) refers to the linking of production and pricing of ancillary services with that of energy. Ancillary services are services a market player can provide that restore short-term imbalances (frequency) in the grid by dispatching resources. The energy market is a spot market wherein traders trade energy commodities in different timeframes (day-ahead, intraday etc.). The general distinction in a co-optimized market model is twofold. There is an energy market and an ancillary services or balancing market.[4] The ancillary services market typically distinguishes two type of offers; (1) regulation services, services that aim to maintain constant frequency, and (2) contingency services, services that remedy unexpected need for power on short notice (e.g. blackouts). Co-optimizing includes the 'opportunity cost' and the short-term restraints of power producing modules and optimizes full economic output (Read, 2010, p. 308). It is generally computed through a Scheduling, Pricing and Dispatch (SPD) model.

There are typically three types of optimizing of the energy and ancillary markets:

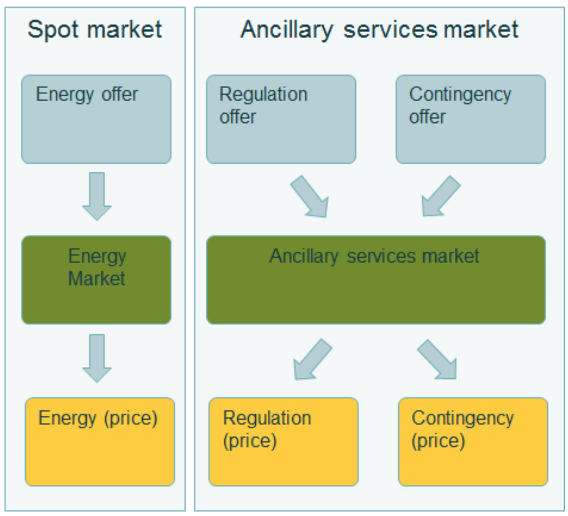
Sequential optimisation:

- Separate markets for energy and ancillary services
- Ancillary services market has two separate markets
- Optimisation of the ancillary services happens after (or before) optimisation of the energy market



Simultaneous optimisation

- An optimized ancillary services market
- A separate ancillary services and energy market
- Optimisation of the ancillary services happens simultaneously to optimisation of the energy market



[4] 'Ancillary services market' is the opted choice in this appendix, but different countries refer to different names as 'reserve market' or 'balancing market'.

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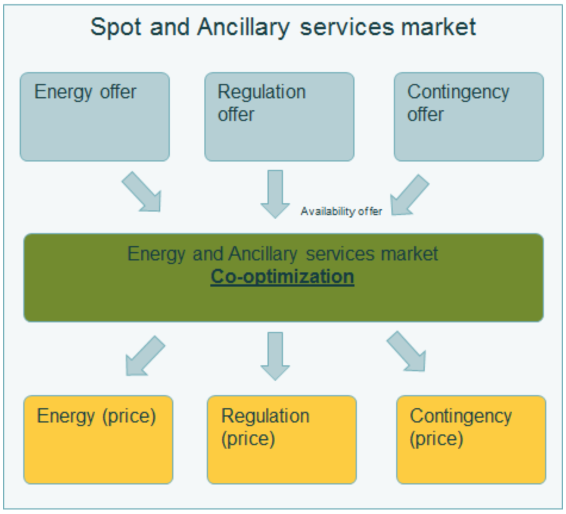
Simultaneous co-optimisation

- Fully linked energy and ancillary services market:
  - single offer with energy component and an ancillary service component
  - ancillary service component is an availability offer
  - availability offers may include costs plus a risk premium
- Recognizes trade-off between ancillary services and energy
- Generators are indifferent to providing ancillary services or energy



Source: Indian utility regulatory commission presentation September 2007, Jerry Webb.

Co-optimisation is being used in various markets. The first to use co-optimizing was New Zealand. Later markets in Australia, Canada, Singapore and the US followed suit. In the Network Codes on Electricity Balancing the EU also foresee in the use of co-optimisation for cross-zonal capacity allocation, albeit this is not the same type of co-optimizing as in the other markets.

New Zealand introduced in 1996 co-optimisation. Its national grid is characterized by a stretched grid, one HVDC cable connection between its two main islands and a hydro-power generation surplus in the south. The co-optimisation is done by a Scheduling, Pricing and Dispatch (SPD) model that utilizes offers from generators, consumer and ‘reserve’ providers. The reserve consists of contingency reserve services, in case of black-outs, and regulation services, to main constant frequency.

Australia also incorporated an energy and reserve co-optimisation in its market design. The Australian Energy Market Operator has the responsibility to operate a spot-market for reserve. They introduced a more complex co-optimisation model in which market players have a choice between more products (2 for regulation and 6 for contingency) related to different timeframes (6 seconds, 60 seconds and 5 minutes). Co-optimisation is only used for Frequency Controlled Ancillary Services (FCAS). Other type of ancillary services, Network Controlled Ancillary Services (NCAS) and System Restart Ancillary Services (SRAS), are procured through long term ancillary contracts. The FCAS market is optimized together with the energy market.

In Northern-America various states and system operators use co-optimisation and refer to it as joint optimisation. They also use additional definitions for the type of ancillary services. Ancillary services are called ‘operating reserves’ and contingency reserve services are divided in ‘supplemental reserve’ and ‘spinning reserve’. Supplemental reserve is not directly synchronized to the grid whilst spinning reserve is. Both types of reserve can supply energy within 10 minutes.

Ontario (Canada) incorporated a joint optimisation system. Joint optimisation is utilized for the energy market and the so-called operating reserve. Joint optimisation in Ontario distinguishes three markets of operating reserve (10-minute spinning, 10 minute non-spinning and 30 minute non-spinning). Market participants can place offers in any of the three markets.[5]

In the United States of America, joint optimisation is being used by the Independent System Operators (ISO), e.g. PJM. ISOs are often responsible for system operation in various states. In their model, PJM distinguishes ‘regulation’ services from ‘synchronized reserve’. The former referring to automatic controlled services that can be used within 5 minutes and respond to frequency

[5] For further elaboration and a price / economic gain example, see http://www.ieso.ca/imoweb/pubs/training/QT20_JointOptimization.pdf.

fluctuations, and the latter referring to an unexpected need for more power (short time), like in blackouts. In the US, the ISO optimisation of balancing markets has evolved along the three models described above in Table 1.

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