Cross-border Exchange and Sharing of Generation Reserve Capacity

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Electricity balancing is the continuous process, in all time horizons, through which Transmission System Operators (TSOs) ensure that a sufficient amount of upward and downward reserves are available to deal with real-time imbalances between supply and demand in their electricity transmission system. Imbalances occur due to forecast errors of demand and renewable supply, and unforeseen events such as line failures and generation outages. To ensure that sufficient reserves are available for real-time balancing, TSOs procure an amount of reserves – so-called reserve capacity or balancing capacity – in advance.

Since system frequency is shared within a synchronous network, persistent imbalances in part of the network can lead to a widespread blackout throughout the network. To prevent this `Tragedy of the Commons', all TSOs in a synchronous area are obliged to provide sufficient reserves. Network codes and guidelines stipulate the reserve requirements that a TSO should meet.

Under the impulse of increasing renewable energy integration, supranational legislation (ENTSO-E,

2014), and a general drive for more cost efficiency and reliability, some TSOs have started to coordinate electricity balancing and reserve procurement between neighbouring TSO zones. Often cited benefits of cross-border balancing and reserve procurement include reduced reserves needs (NREL, 2011); a more efficient use of electricity generation, including reduced renewable energy curtailment (Mott MacDonald, 2013); a higher reliability level; a standardization of the rules and products, which creates a level-playing field; improved market liquidity, which increases competition (Hobbs et al., 2005); and internalisation of external effects on neighbouring TSOs (Tangerås, 2012).

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DEGREES OF CROSS-BORDER COOPERATION

Cross-border cooperation yield benefits both in procurement of reserve capacity and activation of balancing energy. Table 1 structures the different degrees of cooperation that are possible in procurement and in activation.

PROCUREMENT of reserve capacity	ACTIVATION of balancing energy
to meet the reserve requirements resulting from reserve dimensioning	to meet real-time imbalances resulting from forecast errors and unforeseen events
Autarky: no cross-border cooperation **Exchange**: procure reserves in other zones **Sharing**: multiple zones take into account the same reserves	**Autarky**: no cross-border cooperation **Imbalance netting**: avoid counteracting activation **Exchange**: activate reserves in other zones

Table 1: Degrees of cooperation in cross-border balancing between TSO zones

Imbalance netting avoids counteracting activation of balancing energy in adjacent TSO zones. For example, activating upward reserves in response to a negative imbalance in one TSO zone, and separately activating downward reserves in response to a positive imbalance in another TSO zone, is inefficient since counteracting imbalances naturally net out on synchronous networks. Imbalance netting is a constrained version of exchange of balancing energy.

Exchange of balancing energy is a further degree of cooperation in activation of balancing capacity. It implies that cooperating TSOs construct a common merit order of balancing energy bids and select the least-cost activation that meets the net imbalance of the joint TSO zone. Imbalance netting and exchange of balancing capacity increase supply efficiency by decreasing the activation costs.

Reserves exchange makes it possible to procure part of the required level of reserves in adjacent TSO zones. These reserves are contractually obliged to be available for activation by the contracting TSO and they can only contribute to meeting this TSO's required level of reserves. Reserves exchange changes the geographical distribution of reserves. More reserves are procured in cheap TSO zones and less in expensive TSO zones. Reserves exchange also increases supply efficiency by decreasing the procurement costs.

Reserves sharing is a further degree of cooperation in procurement. It allows multiple TSOs to take into account the same reserves to meet their reserve requirements resulting from reserve dimensioning. A TSO in need of balancing energy can use this shared capacity, if other TSOs do not. Reserves sharing leads to both supply efficiency and dimensioning efficiency.

BENEFITS OF CROSS-BORDER COOPERATION

Our model studies analytically the efficiency gains of cross-border cooperation in reserves procurement. Broadly, cooperation increases supply efficiency and dimensioning efficiency.

- **Supply efficiency**: balancing services, both procurement of reserve capacity to meet reserve requirements and activation of balancing energy to meet real-time imbalances, are supplied by the cheapest balancing service providers. That is, if the market is enlarged, expensive balancing services in one part of the market can be substituted for cheaper ones in a different part of the market. The scope for supply efficiency depends on the difference of procurement and activation costs between cooperating TSO zones.
- **Dimensioning efficiency**: less reserve capacity is needed if a TSO in need of capacity can use idle reserve capacity of adjacent TSO zones. The scope for dimensioning efficiency depends on the correlation of imbalance variability between cooperating TSO zones.

Our model analytically derives the optimal procurement of reserve capacity, and the resulting procurement and interruption costs, for both TSO zones for the three degrees of reserve procurement cooperation: autarky, reserves exchange and reserves sharing.

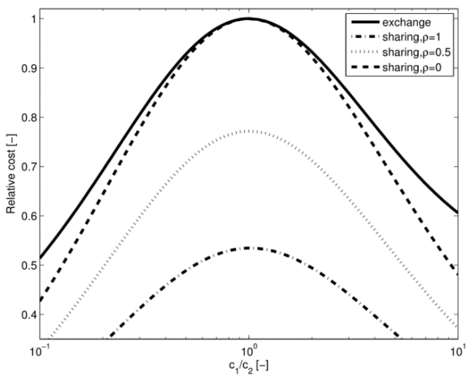

Figure 1: Relative cost of reserves exchange and reserves sharing, as a function of cost asymmetry (c_2/c_1) and reserve needs correlation (p).

Figure 1 displays numerical results from a parameterized example and shows that benefits increase when reserve procurement costs become more asymmetric and reserve needs are less correlated. With low cost asymmetry and low correlation, reserves sharing yields the major part of the cost reduction, while with high cost asymmetry and a high correlation, reserves exchange yields the major part of the cost reduction. With symmetric costs and high correlation, cross-border cooperation in reserves yields limited benefits. We also show that the relative gains of cooperation decrease if TSO zones differ in size and that sharing reduces the total amount of procured reserves and increases the reliability level by allowing cooperating TSOs in need of balancing energy to use the shared capacity.

INCENTIVES FOR CROSS-BORDER COOPERATION

Overall social surplus improves with each step in cooperation. But this entails distributional consequences. With reserves exchange, procurement costs will fall in one zone and rise in the other. With reserve sharing there are distributional consequences both for costs and expected interruptions. These may create disincentives for TSOs focused on procurement cost efficiency and consumer surplus. To ensure cooperation in exchange and sharing, contracts are needed that guarantee all cooperating TSOs a proper portion of the benefits. A benchmark contract involves a lump-sum payment from the high-cost to the low-cost TSO. If this side-payment is determined using Nash bargaining, the overall surplus resulting from exchange or sharing is split evenly between the TSOs so their post-payment surplus improves by the same amount.

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