Cross-border exchange and sharing of generation reserve capacity

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Overview

Most power transmission networks are connected to neighbouring networks. Since system frequency is shared on all voltage levels, power system reliability is considered to be a common good. That is, a non-excludable but rival good. This means that a MW of power can only be used once and that it is technologically difficult to prevent interconnected Transmission System Operators (TSOs) from using more than they provide. Underprovision of reserves in one TSO zone could thus lead to a widespread blackout throughout the synchronous area. To prevent this `Tragedy of the Commons', all TSOs in a synchronous area are obliged to provide sufficient reserves.

National power markets are increasingly interconnected in Europe, spurred by European Regulations, Directives and network codes. In the day-ahead market there has been considerable progress in coupling national markets at the regional level, however, cooperation in balancing has been minimal and limited to a few voluntary agreements. The European Network Code on Electricity Balancing (ENTSO-E, 2014) discusses how TSOs ought to cooperate but does not specify the factors that determine the gains from cooperation and the details of the needed contracts.

We show formally how the efficiency increase from cross-border balancing depends on the cost asymmetry and the correlation of balancing needs between cooperating TSOs. Cooperation decreases costs in two ways:

(A) Cost arbitrage: if the reserve market is enlarged, expensive reserves can be substituted for cheaper procurement and dispatch of reserves.
(B) Pooling of reserve needs: less reserve capacity is needed if idle reserve capacity can be used in neighbouring TSO zones in need of capacity.

The network code distinguishes two degrees of cross-border balancing cooperation: 'exchange of reserves' and 'reserves sharing'. Exchange of reserves makes it possible to procure part of the required level of reserves in adjacent TSO zones, while reserves sharing allows multiple TSOs to take into account the same reserves to meet their reserve requirements. Exchange of reserves only allows cost arbitrage (A), while reserves sharing allows both cost arbitrage and variance-reducing pooling of reserve needs (A)+(B).

The second part of the paper departs from the aggregate analysis of cross-border cooperation and considers the individual costs of cooperating TSOs. TSOs only cooperate if it decreases their procurement costs, while not endangering the reliability of their TSO zone. We show how individual balancing and interruption costs depend on the procurement payment method and the rationing priority rules used. Whenever more side-payments are required, cooperation tends to be more difficult.

Methods

Our model studies reserves sharing and exchange between two TSO zones $i = 1,2$. The need for reserves in TSO zone i at a certain instant is r_i [MW]. This is the real-time imbalance due to a combination of forecast errors of demand and intermittent supply, and failures of generation capacity or transmission components. We denote the joint probability density function of the reserve needs r_i by $f(r_1, r_2)$; r_1 and r_2 are assumed to be non-negatively correlated and jointly normal with known parameters. The TSO's variable of choice is R_i [MW], the quantity of reserves procured. Costs of procuring R_i MW of reserve capacity in TSO zone i are given by $\gamma_i(R_i)$, with γ_i increasing, smooth and convex. Interruption costs are linear in the quantity of energy not supplied to customers.

The order of events in the model is as follows:

1. The TSO at node i chooses ex ante how much reserve capacity R_i to procure and pays a procurement payment to balancing service providers in its own region and to neighbouring TSOs.
2. In real time the actual need for reserves r_i is observed in each zone i.
3. The procured reserves are used to accommodate the reserve needs. In case local reserves are insufficient, TSOs will use exchanged or shared reserves, or ration consumers.

This model analytically derives the optimal procurement of reserve capacity, and the resulting procurement and interruption costs, for both TSO zones for three regimes: autarky, reserves exchange and reserves sharing. In addition, we show how individual balancing and interruption costs depend on the procurement payment method (pay-as-bid vs. pay-as-cleared, capacity vs. energy payments, and use of unshared bids) and the rationing priority rules (reserves-providing vs. reserves-receiving TSO priority) used.

Results

Figure 1 shows that the 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 very little benefits. Lastly, with reserves sharing procured reserves decrease with decreasing correlation.

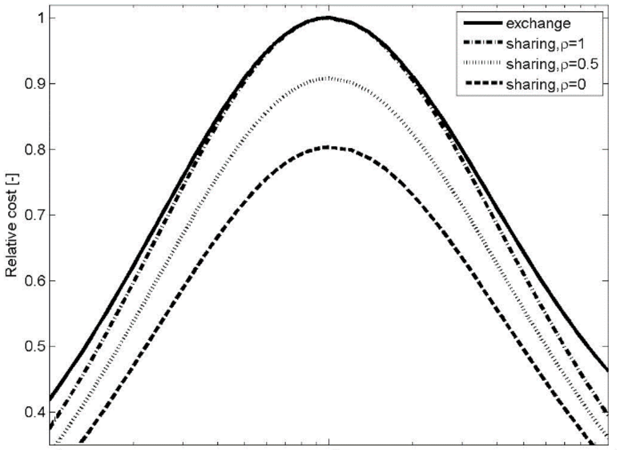

Figure 1 Relative cost (compared to autarky) with reserves exchange and reserves sharing, as a function of cost asymmetry (c_2/c_1) and correlation (ρ) between the reserve needs.

Table 1 shows individual procurement and interruption costs for both TSO zones for a pay-as-cleared capacity auction and rationing priority for the reserves-providing TSO. Implementing these rules makes reserves exchange an improvement for the expensive TSO but not for the inexpensive one. However, with rationing priority for the reserves-providing TSO and a low correlation, sharing is Pareto-improving. That is, both TSOs face lower costs.

	R_1	R_2	R	Relative reserves	PC_1	IC_1	PC_2	IC_2	Total cost	Relative total cost
Autarky	21.21	23.49	44.70	100%	1799	305	1104	158	3366	100%
Exchange	14.90	29.80	44.70	100%	1264	305	1401	158	3128	92.9%
Sharing $\rho = 1$	15.04	30.08	45.12	100.9%	1357	397	1357	19	3131	93%
Sharing $\rho = 0.5$	13.30	26.59	39.89	89.2%	1061	301	1061	13	2436	72.4%
Sharing $\rho = 0$	11.17	22.33	33.50	74.9%	748	204	748	8	1707	50.7 %

Table 1 Reserves [MW] and costs [€/hour] in TSO zone 1 and 2: $c_1 = 2$, $c_2 = 1$ (PC=procurement cost, IC = interruption cost)

Conclusions

This paper compares three degrees of TSO cooperation in generation reserves provision: autarky, reserves exchange and reserves sharing. We derive analytically the optimal procurement of reserves in each of the three cases and show that costs decrease with cooperation. The benefits of reserves exchange and reserves sharing depend on cost asymmetry and correlation of reserve needs between the TSO zones. When TSO zones have highly asymmetric costs and highly correlated reserve needs, reserves exchange already yields large cost reduction. When TSO zones have fairly equal reserve procurement costs but a low degree of reserve needs correlation, reserves sharing is needed to reap the full benefits of TSO reserves cooperation. Lastly, the individual procurement and interruption costs depend on the procurement payment and rationing priority rules used by the cooperating TSOs.

References

ENTSO-E, ”Network Code on Electricity Balancing”, August 2014.

ENTSO-E, ”Network Code on Load-Frequency Control and Reserves”, June 2013.

G.L. Doorman, R. Van der Veen, ”An analysis of design options for markets for cross-border balancing of electricity”, Utilities Policy, 27, 2013.

A.F. van der Weijde, and B.F. Hobbs, ”Locational-based coupling of electricity markets: benefits from coordinating unit commitment and balancing markets”, Journal of Regulatory Economics, 39(3), 2011.