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Cross-border reserve markets: network constraints in cross-border reserve procurement

Kenneth Van den Bergh[a], Kenneth Bruninx[a,b,c], Erik Delarue[a,c,*]

[a] KU Leuven, Celestijnenlaan 300 box 2421, B-3001 Leuven, Belgium
[b] VITO, Boerentang 200, B-2400 Mol, Belgium
[c] EnergyVille, Thor Park 8310, B-3600 Genk, Belgium

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ABSTRACT

Cross-border reserve markets—the procurement and activation of reserves in one control area to maintain system balance in another control area—can lead to increased cost-efficiency and reliability. However, network constraints impose limits on cross-border reserve coordination. Transmission capacity allocation in the reserve market is a complex problem, as it happens under uncertainty and interferes with transmission capacity allocation in energy markets. This paper studies network constraints in the reserve procurement phase, by means of a simulation model and scenario analysis. Three different approaches are proposed and evaluated based on a case study of the Central Western European electricity system. Towards this aim, a dedicated model is developed to simulate the day-ahead energy market, the day-ahead reserve procurement and the real-time reserve activation. In a case study of the Central Western European power system, we show that the best reserve market outcome—weighing cost-efficiency and system reliability—is obtained when reserve activation scenarios are considered in the procurement phase. Policy makers should design, in close cooperation with regulators and system operators, efficient and robust transmission capacity allocation procedures for cross-border reserve markets. This paper can help them to do so as it demonstrates the impact of transmission capacity allocation on cross-border reserve markets.

1. Introduction

Cross-border reserve markets are gaining attention in academia and industry, in light of the prospect of increased cost-effectiveness and enhanced system reliability. In European reserve markets, Transmission System Operators (TSOs)—who bear the final responsibility to balance the generation and consumption of electrical energy on an instantaneous basis within their control area—procure and activate operational reserves to maintain the system balance (ENTSO-E, 2014a).

Today, reserve markets in Europe are mainly national markets. Although certain exceptions exist, the basic rule is that every control area is responsible for the dimensioning, procurement and activation of its reserves (Baldursson et al., 2016). In cross-border reserve markets, TSOs can activate and/or procure reserves in other control areas. Moreover, the dimensioning of reserves can be coordinated between different control areas. It is generally accepted in the scientific literature that cross-border reserve markets increase social welfare and operational reliability, since the amount of reserves needed in the system can be decreased (due to spatial smoothing of imbalances) and the cost of procuring and activating reserves can be reduced (due to spatial arbitrage between different control areas) (Vandezande et al., 2010).

An important issue that is underexposed in the scientific literature and network codes is how cross-border network constraints should be taken into account. Cross-border reserve markets are constrained by the available cross-border transmission capacity. In reserve markets, reserve capacity is procured by TSOs before real-time and—if needed—activated in real-time to deal with system imbalances. In this respect, one should distinguish between reserve procurement—which refers to scheduling of reserve capacity before real-time—and reserve activation—which refers to activating reserve capacity to deliver or consume energy in real-time. Transmission capacity allocation for

* Corresponding author at: KU Leuven, Celestijnenlaan 300 box 2421, B-3001 Leuven, Belgium.
E-mail address: erik.delarue@kuleuven.be (E. Delarue).

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Nomenclature

Superscripts

DA day-ahead energy market
RP day-ahead reserve procurement
RT real-time reserve activation

Sets

I (index i) set of all power plants
I^s subset of power plants which can deliver spinning reserves
I^{ns} subset of power plants which can deliver non-spinning reserves
L (index l) set of transmission lines
N (index n) set of nodes
T (index t) set of time steps

Parameters

$A_{l,n}$ network incidence matrix, $A_{l,n} \in \{0,1\}$
$AI_{n,i}$ matrix linking power plant i to node n, $AI_{n,i} \in \{0,1\}$
C_i generation cost of power plant i at minimum power output [EUR/h]
$DEM_{n,t}$ load at node n at time step t [MW]
$\overline{F^{min}}_l$, $\overline{F^{max}}_l$ minimum and maximum power flow through line l [MW]
$\overline{P_i}$ maximum power output of power plant i [MW]
$\underline{P_i}$ minimum power output of power plant i [MW]
$RES_{n,t}$ renewable generation at node n at time step t [MW]
$R_n^{ns,+}$ upward non-spinning reserve requirement at node n [MW]
$R_n^{s,+}$ upward spinning reserve requirement at node n [MW]
$R_n^{s,-}$ downward spinning reserve requirement at node n [MW]
MC_i marginal generation cost of power plant i [EUR/MWh]
MDT_i minimum down time of power plant i [h]
MUT_i minimum up time of power plant i [h]
SUC_i start-up cost of power plant i [EUR/start]

Variables

$\Delta^+ f_{l,t}$, $\Delta^- f_{l,t}$ flow through line l due to reserve activation at time step t [MW]
$p_{n,t}$ network injection at node n at time step t [MW]
$f_{l,t}$ flow through line l at time step t [MW]
$g_{i,t}$ power output above minimum output of power plant i at time step t [MW]
$rs_{i,t}^+$ upward spinning reserve provided by power plant i at time step t [MW]
$rs_{i,t}^-$ downward spinning reserve provided by power plant i at time step t [MW]
$v_{i,t}$ start-up-state of power plant i at time step t, $v_{i,t} \in \{0,1\}$
$w_{i,t}$ shut-down-state of power plant i at time step t, $w_{i,t} \in \{0,1\}$
$z_{i,t}$ on/off-state of power plant i at time step t, $z_{i,t} \in \{0,1\}$
$z_{i,t}^{ns}$ non-spinning delivery state of power plant i at time step t, $z_{i,t}^{ns} \in \{0,1\}$

reserve activation is a problem with a deterministic character, while transmission capacity allocation for reserve procurement has a stochastic character.[1] At the moment that reserve capacity is activated to deliver or consume energy (i.e., in real-time), the system state is known. In other words, the remaining cross-border transmission capacity is known and the impact of activating cross-border reserves on the network can be determined. As such, network constraints in the reserve activation can be taken into account in the same way as network constraints are taken into account in the (day-ahead and intra-day) energy market. At the moment that reserve capacity is procured (i.e., before real-time), the system state is still unknown: it is uncertain whether the procured reserve capacity will be actually activated in real-time and what the remaining real-time cross-border capacity will be at that time. Therefore, it is not straightforward to take network constraints into account in the cross-border procurement of reserves.

This paper proposes a novel approach to include network constraints in the cross-border procurement of reserves. The 2013 Central Western European electricity system (Belgium, Luxembourg, France, Germany and the Netherlands) is considered as a case study. The contributions of this paper to the existing scientific literature are twofold:

1) The paper presents a (deterministic) model of the reserve market that takes account of network constraints in cross-border reserve procurement. Our model allows mimicking optimal arbitrage between reserve, energy and transmission capacity markets. Moreover, the model fully considers the real-time reserve activation, simulating the balancing market outcome, and includes intertemporal constraints on the operation of the thermal power plants;
2) The paper quantifies the benefits of cross-border procurement and activation of reserves for the Central Western European system in an extensive case study.

This paper deals only with short-term operational reserves. Long-term reserves—relevant in the framework of system adequacy—are not considered (Luickx et al., 2008). Operational reserves are defined as all possible flexibility options within an electricity system to respond to changes in load or generation within the time frame of minutes to hours (Lannoye et al., 2012). Reserves can be delivered by conventional power plants, demand response, energy storage units and curtailment of renewables (Cochran et al., 2014).

This paper deals with reserve markets in Europe. European reserve markets are characterized by a zonal approach (i.e., every country is—roughly speaking—one control area with one reserve market and assumed to be a copper plate[2]) and separate energy and reserve market.

The paper continues as follows. Section 2 discusses the current reserve market design in Europe and gives an overview of the scientific literature on the integration of reserve markets. Section 3 presents the generation scheduling model (i.e., a unit commitment model) developed for this study and the considered scenarios. Section 4 discusses the case study of the Central Western European power system. Results are presented and discussed in Section 5. Section 6 concludes and formulates policy recommendations.

2. Cross-border reserve markets

This section starts off with an overview of reserve markets in the

[1] In reality, transmission capacity allocation for reserve activation and electrical energy also has a stochastic character as the transmission capacity offered to the real-time market may not be physically available, caused by the zonal market approach applied in Europe. Such effects are however not considered in this paper and the reserve activation is executed assuming perfect foresight on the available transmission capacity. In contrast, the stochasticity in the transmission capacity allocation for reserve procurement is caused by the inherent uncertainty of reserves being activated and the unknown state of the network at that moment. This effect is considered in full in this paper.

[2] Network constraints within a control area are not considered, only network constraints between control areas (i.e., cross-border) are dealt with in this paper.