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Benefits of coordinating sizing, allocation and activation of reserves among market zones

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ABSTRACT

Due to the increased penetration of intermittent renewables, operating reserves are becoming increasingly important in electricity markets. Coordinating the sizing, allocation and activation of reserves among market zones can decrease operational costs and enhance system reliability. However, network limitations constrain reserve coordination among zones. This paper investigates the value of interzonal coordination of reserve sizing, allocation and activation. A series of three models that simulate unit commitment and dispatch decisions within network-constrained markets simulate the impact of intermarket coordination of each of these sets of decisions. A case study for the Central Western European electricity system indicates that such coordination can lower operational costs and increase system reliability. However, the best performing strategy for the considered case study turns out to be a strategy with coordinated activation but uncoordinated sizing and allocation of reserves due to suboptimal coordination of sizing and allocation with activation. In particular, because transmission constraints are simplified when sizing and allocating reserves, reserves might not actually be deliverable to where renewable output is different from forecast.

1. Introduction

Short-term reserves are needed in electricity systems to balance demand and supply at all times. Short-term reserves or operational flexibility is defined as the ability of a system to deploy its resources to respond to changes in load or generation within the time frame of minutes to hours [1]. Electricity systems have always embedded a certain level of flexibility in order to deal with variable load, load forecast errors and unexpected power plant or transmission outages. However, short-term reserves are gaining importance in todays electricity markets due to the rapid growth of intermittent renewable sources [2]. Intermittent renewables, such as wind and solar photovoltaics, are characterized by variable output that is only partially predictable and dispatchable. As a result, the need for short-term reserves has increased in systems with large amounts of intermittent generation from wind and solar photovoltaics [3].

An important source of reserves in todays electricity systems is the flexible operation of conventional generation units [4]. Conventional generation units can deliver reserves by ramping-up or down (i.e., spinning reserves), and starting-up or shutting-down (i.e., non-spinning reserves). It is, however, uncertain whether today's fleet of conventional generators is able to deliver enough reserves to deal with an increasing penetration of intermittent renewables [5]. Therefore, other operational flexibility options such as storage, demand response and curtailment of excess generation from renewables, are extensively discussed in the academic literature and policy documents [4]. More flexible operation of the power system can also be obtained by coordinating reserve procurement and deployment among different market zones. As a result, system imbalances can be netted and the least costly generation unit, although possibly located in another market zone, can be scheduled and activated to deliver reserves.

This paper focuses on reserves delivered by conventional power plants under various degrees of coordination between market zones. We simulate the following general procedure for operational reserve planning: (1) sizing of the need for reserves (i.e., how many MW of reserves should be scheduled day-ahead), (2) day-ahead

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Nomenclature

Sets

$i \in I$	set of power plants
$i^{nsr} \in I^{nsr}$	subset of power plants delivering non-spinning reserves
$l \in L$	set of transmission lines
$n \in N$	set of nodes
$s \in S$	set of reserve zones
$t \in T$	set of time steps (quarter-hour)

Parameters

$A_{l,n}$	network incidence matrix
$A^{plant}_{n,i}$	matrix linking power plant i to node n {0,1}
$A^{rsr}_{s,i}$	matrix linking power plant i to spinning reserve zone s {0,1}
$D_{n,t}$	load at node n at time step t (MW)
$\overline{F}_l$	maximum flow through line l (MW)
$\underline{F}_l$	minimum flow through line l (MW)
LCC_n	load curtailment cost (0.25 EUR/MWh)
MC_i	marginal generation cost (0.25 EUR/MWh)
MDT_i	minimum down time of power plant i (quarter-hour)
MUT_i	minimum up time of power plant i (quarter-hour)
NC_i	generation cost at minimum output of power plant i (EUR/quarter-hour)
$\overline{P}_i$	maximum power output of power plant i (MW)
$\underline{P}_i$	minimum power output of power plant i (MW)
RCC_n	renewables curtailment cost (0.25 EUR/MWh)
$RES_{n,t}$	renewable generation at node n at time step t (MW)
SUC_i	start-up cost of power plant i (EUR/start-up)
SR^+_s	required upward spinning reserve in reserve zone s (MW)
SR^-_s	required downward spinning reserve in reserve zone s (MW)

Variables

$f_{l,t}$	power flow through line l at time step t (MW)
$g_{i,t}$	power generation of power plant i above minimum output at time step t (MW)
$lc_{n,t}$	load curtailment at node n at time step t (MW)
$p_{n,t}$	power injection in the grid at node n at time step t (MW)
$r^+_{i,t}$	scheduled upward spinning reserve from power plant i at time step t (MW)
$r^-_{i,t}$	scheduled downward spinning reserve from power plant i at time step t (MW)
$rc_{n,t}$	renewables curtailment at node n at time step t (MW)
$v_{i,t}$	start-up status of power plant i at time step t {0,1}
$w_{i,t}$	shut-down status of power plant i at time step t {0,1}
$z_{i,t}$	on/off-status of power plant i at time step t {0,1}

allocation of reserves (i.e., which flexible units are scheduled to provide those reserves in real-time) and (3) real-time activation of reserves (i.e., which reserve capacity actually provides regulation services in real-time if needed).

Note that the term reserve is used in this paper and not the more general term operational flexibility. In this paper, reserves refer to the short-term flexibility that can be delivered between day-ahead scheduling and real-time by conventional generation units in order to deal with renewables forecast errors. This definition of reserves is different from the definition typically used in the context of transmission system operators (TSOs). TSOs contract reserves and activate them in real-time to maintain the real-time system balance. This paper, however, not only considers TSO reserves but also intra-day schedule adjustments by generators and consumers.[3] Furthermore, this paper focusses only on reserves needed to deal with renewables forecast errors, not with other sources of uncertainty such as load forecast errors or contingencies.

The benefits of coordinating activation of reserves are widely accepted in the literature. Meeus et al. [6] and Vandezande et al. [7] emphasize the importance of cross-border balancing in a cost-effective and efficient electricity market. Van der Weijde and Hobbs [8] quantify the cost savings that arise from the coordination of real-time markets for a simple 4-node system. Cost savings turn out to be always positive, but the exact magnitude of the savings depends on various system parameters such as cross-border transmission capacity. A similar analysis is performed by Oggioni and Smeers [9]. They show, based on an illustrative network, that coordination between different system operators can reduce the cost of real-time counter-trading. Vandezande et al. [10] estimated that the balancing costs in Belgium and the Netherlands could have been 40% lower in 2008 if cross-border balancing were in place. But despite these apparent benefits, coordination of real-time and balancing markets is still limited in Europe [11].

While some papers explore reserves and balancing, they do not explicitly consider cross-border coordination of reserve sizing and allocation. The coordination of the sizing and allocation phases is more complex since the future system state is uncertain, whereas reserve activation happens in real-time when the system state is known. As such, deliverability of procured and scheduled reserves cannot be guaranteed since transmission constraints can hinder real-time reserve activation. One possible approach to including transmission constraints in coordinated sizing and allocation is to consider post-contingency states in the reserve allocation model [12]. Another approach is to make reserve zones dynamic and adjust them to changing system states [13,14]. However, both approaches are not applicable to the current deterministic and zonal European market design. The nature of European (reserve) markets implies that reserve sizing, allocation and activation are three fully separated steps. As such, the probability that reserves are being activated (which can be mathematically represented by a set of post-contingency states) is not taken into account when allocating or sizing these reserves. Besides, the zonal nature of European (reserve) markets imply that fixed reserve zones are being used (which typically coincide with national borders). As such, it is currently not possible to adjust the set up of reserves zones over time (e.g., from week to week or month to month).

This paper builds upon and generalizes the existing literature. Our work makes two contributions:

(1) We investigate whether it is beneficial for market zones to coordinate sizing, allocation, and activation of reserves. Towards this aim, models are developed that determine the optimal sizing, allocation and activation of reserves, with and without coordination between market zones. The full procedure for operational reserve planning is studied in this work: sizing, allocation and activation.
(2) Coordinating reserve sizing and allocation can lead to cost reductions due to spatial smoothing of forecast errors and spatial arbitrage. However, coordination can also lead to sub-optimal market outcomes as network constraints are typically

[3] The intra-day market is considered implicitly in this study – not explicitly – by comparing day-ahead forecasts with actual measurements (as such spanning the intra-day and the real-time market) and by giving more flexibility to the real-time phase than strictly available (as such allowing actions taken in the intra-day market).