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Impact of harmonised common balancing capacity procurement in selected Central European electricity balancing markets

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HIGHLIGHTS

- Shortening timing and length of balancing products reduces costs, CO_2 emissions and RES-E spillage.
- Short timings and lengths are an appropriate premise to integrate RES-E and DER.
- DER save millions on top of new balancing market designs.
- Symmetric procurement of up- and downward balancing is a poor design for RES-E.
- Co-optimisation of energy and reserve has a noteworthy potential in Europe.

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ABSTRACT

Contrary to the U.S., where the Independent System Operator is responsible for electricity balancing, in Europe this is the task of Transmission System Operators. Also in terms of market implementation there are fundamental differences between the U.S. (co-optimisation of day-ahead and balancing/ancillary markets) and Europe (separate bidding and clearing in different market segments).

This paper focuses on European electricity markets, where recently the framework for upcoming challenges in electricity balancing has been defined ("Network Code on Electricity Balancing"). In detail, different possible (cross-border) balancing market designs in Europe are evaluated using the model EDisOn + Balancing. We focus on the procurement of up- and downward balancing capacity products (conducted jointly or separately), and how common procurement of frequency restoration reserves influences wholesale electricity market clearings. Different timings and lead-times for the procurement of automatically activated frequency restoration reserve are investigated, starting from weekly off-peak and peak products, leading to daily four-hour products.

The quantitative results confirm that in addition to asymmetric procurement of up- and downward balancing capacity, common procurement has significant advantages in terms of cost reductions. The shortening of balancing product timings supports the integration of renewable electricity generation essentially.

To achieve these positive effects, the first focus should be on harmonising national balancing markets Europe-wide. A best practise case is the pilot project between Germany and Austria: the two countries have already started common activation of automatic frequency restoration reserve and there are plans for future common procurements.

Nomenclature

The sets with corresponding indices, parameters and decision variables of the EDisOn + Balancing model are listed below.

Sets and indices

H,Q (index h) set of time steps (H = hours, Q = quarter-hours)
I_{ca} (index i) set of balancing groups in control area ca
CA (index ca) set of control areas (e.g. APG, TransnetBW, etc.)
$L \subset L_{AC} \dot{\cup} L_{DC}$ (index l,l_{AC},l_{DC}) set of transmission power lines
TH_i (index th) set of thermal units in balancing group i
PS_i (index ps) set of pumped hydro storage units in balancing group i
ST_i (index st) set of other storage units in balancing group i
$j \in \{a,m\}$ automatically and manually activated FRR

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Parameters (italic) for the wholesale market:

$C_{th}^{O\&M}$ operations and maintenance costs, EUR/MWh
C_{th}^{fuel} primary energy costs, EUR/MWh
C^{CO_2} CO_2 certificate price, EUR/tCO_2
$SRMC_{h,th}$ short run marginal costs of thermal power plant *th*, EUR/MWh
$C_{h,th}^{Start}$ start costs of thermal power plants, EUR/MWh
C^{Wi},C^{PV} generation costs of wind and PV systems, EUR/MWh
C^{Hy} generation costs of Run-of-River (RoR), EUR/MWh
$VoLL$ value of lost load, EUR/MWh
$Demand_{h,i}$ demand in step *h* and balancing group *i*, MWh/h
$L_i^{up(down)}$ percentage of possible demand increase (decrease) in *i*, %
DT time frame of demand shift, h
$Demand_{h,i}^{heat}$ heat demand in step *h* and balancing group *i*, MWh/h
$ramp_{th}$ ramping limit of thermal power *th*, %
$Cap_{th}^{max(min)}$ max (min) capacity of thermal power plant *th*, MW
Em_{th} CO_2 emissions of thermal power plant *th*, tCO_2/MWh
η_{th} efficiency of thermal power plant *th*, %
η_{th}^{heat} thermal efficiency of thermal power plant *th*, %
Cap_i^{Hy} max capacity of RoR, MW
$Inflow_{h,i}^{hy}$ natural inflow RoR, MWh/h
$Cap_{ps}^{Tu(Pu)}$ max turbine (pump) capacity of unit *ps*, MW
η_{ps}^{Tu},η_{ps}^{Pu} efficiency of turbine and pump, %
$En_{ps}^{min(max)}$ min (max) storage level of pumped hydro storage unit *ps*, MWh
$Infl_{h,ps}$ natural inflow of unit *ps*, MWh/h
$CapOut_{st}$ max charging capacity of storage unit *st*, MW
$CapIn_{st}$ max discharging capacity of storage unit *st*, MW
η_{st}^{stOut},η_{st}^{stIn} efficiency of generation and consumption of other storages, %
$En_{st}^{min(max)}$ min (max) storage level of other storage unit *st*, MWh
$Wind_{h,i}$ generation of wind turbines, MWh/h
$PV_{h,i}$ generation of PV systems, MWh/h
$CapL_l^{A\rightarrow B(B\rightarrow A)}$ capacity limit of transmission power line *l* from A to B (B to A), MW
$A_{l,i}$ incidence matrix, {−1,0,1}
α^{max} maximum of phase shifter angel, 30°
$PTDF_{l_{AC},i}$ power transfer distribution factors of the grid, $\mathbb{R}$
$PSDF_{l_{AC},l_{pst}}$ phase shift distribution factors of the grid, $\mathbb{R}$
$DCDF_{l_{AC},l_{DC}}$ DC lines distribution factors of the grid, $\mathbb{R}$

Parameters (italic) for the balancing market:

$\overline{TC}_{h,th}^{j}$,$\underline{TC}_{h,th}^{j}$ total costs of up-/downward balancing capacity, EUR/MW
$p_{h,i}^{DA}$ expected wholesale price level, EUR/MWh
$V_{h,ps}^{H2O}$ water value of hydro storage unit *ps*, EUR/MWh
$V_{h,st}^{Stor}$ storage value of other storage unit *st*, EUR/MWh
$Peak_h$ Peak = 1, Off-Peak = 0 or Weekend = −1, [1,0,−1]
$\overline{FRR}_{ca}^{j}$,$\underline{FRR}_{ca}^{j}$ necessary up-/downward FRR of control area *ca*, MW/h
z_l capacity share of line *l* for balancing purposes, [0,1]

Decision variables for the wholesale market:

$\mathrm{D}_{h,i}^{up(down)}$ increase (decrease) of demand in hour *h* in node *i*, MWh/h
$\mathrm{D}_{h',h,i}$ ancillary variable for shifting demand from *h′* to *h* in *i*, MWh/h
$\mathrm{thP}_{h,th}$ generation of thermal power plant *th*, MWh/h
$\mathrm{X}_{h,th}^{X}$,$\mathrm{X}_{h,th}^{Y}$,$\mathrm{X}_{h,th}^{Z}$ linearisation of thermal generation, [0,1]
$\mathrm{Str}_{h,th}$ thermal power plant *th* starts or not, [0,1]
$\mathrm{PtoH}_{h,i}$ Power-to-Heat device in balancing group *i*, MWh/h
$\mathrm{tuP}_{h,ps}$,$\mathrm{puP}_{h,ps}$ generation and pump consumption of PHS unit *ps*, MWh/h
$\mathrm{storL}_{h,ps}$ storage level of PHS, MWh/h
$\mathrm{stPOut}_{h,st}$,$\mathrm{stPIn}_{h,st}$ generation and consumption of other storage unit *st*, MWh/h
$\mathrm{storL}_{h,st}$ storage level of other storages, MWh/h
$\mathrm{DCharge}_{h,st}$ stand-by losses, MWh/h
$\mathrm{hyP}_{h,i}$ generation of RoR plants, MWh/h
$\mathrm{Spill}_{h,i}^{Hy}$ RoR spillage (RES-E curtailment), MWh/h
$\mathrm{Spill}_{h,i}^{Wind}$ wind generation spillage (RES-E curtailment), MWh/h
$\mathrm{Spill}_{h,i}^{PV}$ PV generation spillage (RES-E curtailment), MWh/h
$\mathrm{Spill}_{h,ps}^{PHS}$ spillage of natural inflow of PHS, MWh/h
$\mathrm{NSE}_{h,i}$ not supplied energy, MWh/h
$\mathrm{Flow}_{l,h}$ power flow on transmission line *l*, MWh/h
$\mathrm{Exch}_{i,h}$ power injection in node/balancing group *i*, MWh/h
$\alpha_{i,h}$ phase angle of phase shifter in node *i*, °
$\delta_{i,h}$ phase angle in node *i*, °

Decision variables for the balancing market:

$\overline{\mathrm{thFRR}}_{h,th}^{j}$,$\underline{\mathrm{thFRR}}_{h,th}^{j}$ reserved capacity for up-/downward $j \in \{a,m\}$ FRR of thermal unit *th*, MW/h
$\overline{\mathrm{psFRR}}_{h,ps}^{j}$,$\underline{\mathrm{psFRR}}_{h,ps}^{j}$ reserved capacity for up-/downward *j* FRR of pumped hydro storage unit *ps*, MW/h
$\overline{\mathrm{stFRR}}_{h,st}^{j}$,$\underline{\mathrm{stFRR}}_{h,st}^{j}$ reserved capacity for up-/downward *j* FRR of other storage unit *st*, MW/h
$\overline{\mathrm{Exch}}_{h,i}^{j}$,$\underline{\mathrm{Exch}}_{h,i}^{j}$ exchanged reserve capacity for up-/downward *j* FRR, MW/h
$\overline{\mathrm{RCap}}_{l,h}^{j}$,$\underline{\mathrm{RCap}}_{l,h}^{j}$ reserved transmission capacity for *j* FRR on line *l*, MW/h
$\mathrm{storL}_{h,ps}^{RV+}$,$\mathrm{storL}_{h,ps}^{RV-}$ reserved storage level of PHS unit *ps* for up-/downward balancing, MWh/h
$\mathrm{storL}_{h,st}^{RV+}$,$\mathrm{storL}_{h,st}^{RV-}$ reserved storage level of other storage unit *st* for up-/downward balancing, MWh/h

1. Introduction

In U.S. electricity markets a trend is to implement co-optimisation of energy and reserves, i.e. joint energy and reserve market clearing as part of the centralised unit commitment and economic dispatch done by the Independent System Operator (ISO). On the contrary, in Europe mostly sequential energy and reserve markets exist with separate bidding and market clearing mechanisms. These markets are run by different entities, the Power Exchanges and by national Transmission System Operators (TSOs). So there are fundamental differences between U.S. and European electricity markets and it will take several years or even decades to improve or harmonise the market mechanisms Europe-wide. For a comprehensive comparison of several structural and organisational aspects of the U.S. and European electricity markets it is referred to [1,2].

The Agency for the Cooperation of Energy Regulators (ACER) and the European Network of Transmission System Operators for Electricity[1] (ENTSO-E) play a key role in achieving the so-called 'European Internal Energy Market'. The task of ACER has been to propose so-called 'Framework Guidelines', providing the basis for the 'Network Codes' – developed by ENTSO-E – for a European cross-border electricity market and the corresponding integration of large-scale renewable electricity generation (RES-E) in Europe. High shares of RES-E generation require also robust balancing measures and procedures of

[1] ENTSO-E represents 43 TSOs from 36 countries across Europe.