Energy 57 (2013) 106–115

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Approaching wind power forecast deviations with internal ex-ante self-balancing

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ARTICLE INFO

*Article history:*
Received 30 August 2012
Received in revised form
12 March 2013
Accepted 13 March 2013
Available online 30 May 2013

*Keywords:*
Balancing
Electricity market
Nordic power system
Re-scheduling
Stochastic generation
Wind power integration

ABSTRACT

Short-term variations in wind power generation make real-time balancing of load and generation a more challenging task for the Transmission System Operator (TSO). One issue of interest that could facilitate the efficient integration of wind power is to shift larger parts of the balancing responsibility from the TSO to the power generating companies. The idea is to reduce the real-time balancing need for the TSO by demanding power generating companies to minimise their expected imbalances. To comply with this, power generating companies can re-schedule their production based on updated production forecasts. As a key of the contribution, this paper analyses internal ex-ante self-balancing, where this re-scheduling is done shortly before the period of delivery and internally within each power generating company. To quantify the value of such a more distributed balancing responsibility, a model has been developed which consists of a sequence of optimisation models. Then, possible trading decisions of power generating companies are evaluated in different situations. This is based on a hydro-thermal generation portfolio within the framework of the Nordic electricity market.



## 1. Introduction

Wind power generation contributes to a less polluting power supply [1]. But it also raises challenges for the operation of power systems. One example is variations in wind power generation from hour to hour which are hardly predictable in a precise way. When wind power penetration increases, balancing load and generation in real-time becomes a more challenging task for the Transmission System Operator (TSO) [2].

While in some countries, such as Denmark or Spain, wind power is contributing significantly to electricity generation, it does not yet play a major role in Norway, Sweden and Finland as can be seen in Table 1. Nevertheless, Sweden has ambitious targets: by 2020, the power system should be able to accommodate 30 TWh/year of wind power [3], i.e. approximately 20% of 2012's national electricity production Table 1. And with 763 MW newly installed capacity in 2011, the increase of installed wind power capacity (in absolute numbers) was the tenth highest world-wide, according to [4].

Applying *internal ex-ante self-balancing*, a power generating company re-schedules its power plants in order to balance its commitments towards other market participants with the newest production forecast. This is done shortly *before* the hour of delivery (ex-ante) and, in contrast to trading, only affecting the *own* power plants of a power generating company (internal self-balancing).

Due to the challenges connected with strongly increasing wind power penetration levels, this paper explores the question whether enforced balancing within a power generating company that owns several types of power plants can reduce the need for activation of tertiary reserves in the power system. Internal ex-ante self-balancing – which in the following will be referred to only as *self-balancing* – could be advantageous if it leads to efficiency gains from the system's perspective, measured as changes in welfare.

In general, imbalances on the generation side stem from generation forecast errors, outages or other factors that affect the generation available during the hour of delivery. As a consequence, commitments made on the day-ahead and intraday market cannot be met. Those deviations are balanced by the TSO in real-time. The focus in this paper is on deviations in wind power generation. It is therefore assumed that imbalances only stem from wind power forecast errors and the probability of outages in other power plants is neglected. The model would, however, also be applicable to other variable generation, for example, solar power.

Because balancing of wind power deviations comes at a cost [5]; the presented model is relevant for electricity markets where all power generating companies are exposed to imbalance costs for

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http://dx.doi.org/10.1016/j.energy.2013.03.033

**Table 1**
Electricity generation mix and national consumption in the Nordic countries in 2012. Data from monthly production lists for individual countries in Ref. [29].

| | Production [TWh/year] | | | | Total | |
|---|---|---|---|---|---|---|
| | NO | SE | FI | DK | [TWh/year] | Share |
| Hydro | 143 | 71 | 17 | 0 | 231 | 59% |
| Nuclear | 0 | 55 | 22 | 0 | 77 | 20% |
| Fossil | 3 | 4 | 18 | 17 | 42 | 11% |
| Wind | 1.6 | 6.4 | 0.5 | 10.2 | 18.7 | 5% |
| Other RES[a] | 0 | 10 | 10 | 2 | 22 | 6% |
| Total generation[b] | 148 | 146 | 68 | 29 | 391 | 100% |
| *Nat. consumption* | *128* | *127* | *85* | *37* | *377* | – |

[a] Biomass, biogas, solar, landfill gas, sewage treatment plant gas, geothermal, tidal, wave.
[b] Differences due to rounding and non-identifiable generation (FI).

their deviations; i.e. where the TSO, after the hour of delivery, spreads out the balancing costs on those companies that had deviations, as, for example, in many European countries such as France, Poland and the Nordic countries [6]. The model is developed for electricity markets where balancing power is procured in a spot-market *after* the closure of the day-ahead and intraday markets.[1]

To expand the opportunities of market participants to reduce their imbalance volume, i.e. the deviation between their generation during the hour of delivery and to what they have committed themselves on the market, liquid intraday markets are of importance [7,8]. Liquid intraday markets allow market participants to minimise their imbalance costs (producers' perspective). And by adjusting their own deviations, the market participants also reduce the total volume of balancing power that has to be activated (system's perspective). However, often only very small volumes are traded on intraday markets as [7] reveals. In 2012, for example, the traded volume on the Nordic intraday market ELBAS was 3.2 TWh [9], while the sum of the national consumptions amounted to 377 TWh as listed in Table 1. The situations, for example, in Germany and France used to be similar [7] but are now improving [10]. Possible reasons for low traded volumes on intraday markets might be their design as continuous trading platforms (opposed to intraday auctions), the fact that intraday and balancing markets can be substitutes and the design of the imbalance settlement scheme [7].

Reduced trading possibilities on intraday markets are a motivation to investigate *internal* ex-ante self-balancing. Reduced imbalances will result in lower balancing costs for which the companies have to stand. Moreover, larger system imbalances, which are difficult to handle [11], are then less likely to occur. Many models that have been developed to derive optimal bidding strategies, e.g. by multi-stage stochastic programming as in Refs. [8,12] require that the sub-markets (represented by the stages in the problem formulation) are perfectly liquid. However, in this paper, they are assumed to be fully illiquid, i.e. trades on intraday markets are not feasible. In case of ELBAS, this is a more realistic assumption than to assume a perfect intraday market. It can also be supported by the following argument: Assuming that self-balancing can be done shortly before the hour of delivery and directly after closure of the intraday market, it might be reasonable to withhold capacity even from a liquid intraday market. For example, if the own marginal generation costs for re-scheduling actions are lower than the ones of the other power generating companies. In that case, capacity might be withhold to keep an adjustment margin within the own portfolio instead of trading on the intraday market.

An alternative possibility for power generating companies to minimise their imbalance volume would be the coordination between several generating companies to diversify their portfolios and to benefit of negatively correlated characteristics (e.g. wind and hydro in Mid-Norway [13]). Of course, also hedging on the financial market, and the adaptations of bidding strategies to better represent uncertainties could contribute to lower imbalance volumes [8].

The main contribution of this paper is to present a model and to apply it on a test-system in order to analyse the value of self-balancing for the power system. Possible trading decisions for power generating companies are modelled in different situations based on a hydro-thermal generation portfolio within the framework of the Nordic electricity market. The model itself is a sequence of mixed-integer linear optimisation problems to clear different sub-markets. If stronger ex-ante balancing responsibilities would reduce the total variable generation costs of the system, it would be advantageous from the system's perspective. For a detailed description on the Nordic electricity market, we refer to [14,15].

## 2. The model

### 2.1. Overview

Each power plant $i$ is linked to a power generating company $f$. These companies are assumed to act like *balance responsible parties* which – on the Nordic electricity market – are market participants that aggregate production and/or consumption. Those parties have to submit their final production plan to the TSO[2] and are also charged by the TSO for imbalance costs [14]. These costs can, then, be distribute further to those power generating companies that deviated from their commitments. Therefore, we assume that each power generating company faces the costs for its own imbalances.

In the model, imbalances only occur due to imperfect forecast of the wind power generation, i.e. other sources of power generation are assumed to be perfectly predictable during the regarded time horizon of the model.

The model contains three parts: day-ahead trading, balancing market and – in case of self-balancing – an intermediate optimisation step. On each of the decision steps represented here, the power generating companies consider the results from the preceding steps. Trading possibilities on down-stream markets that are cleared at a later point in time are not foreseen by the power generating companies, i.e. we assume that they do, e.g. not consider the future possibility to bid on the balancing market while placing bids on the day-ahead market. For both the day-ahead and the balancing market, perfect competition is assumed. The transmission grid is not yet represented in the model. Hence, the model negelects transmission constraints and there is just one price zone in which the cheapest bids can always be used.

The model is implemented in MATLAB, the optimisation problems are formulated and solved in the program package GAMS using the CPLEX solver and the GDXMRW interface [16]. The model is run repeatedly for 24 consecutive hours. Dependencies between the hours, such as hydrological coupling (several power plants in the same river system), water balances (storage in reservoirs) or start-and-stop constraints in thermal power plants are not considered. Time resolution is 1 h.

[1] In the Nordic countries, the balancing market is referred to as *regulating market*. Furthermore, the term *balancing power* refers there to the energy which the power generating companies buy or sell from/to the TSO to settle their imbalance after the hour of delivery while the term *regulating power* is used for the activated tertiary reserves. In this paper, we follow the terms used by the European Network of Transmission System Operators.

[2] In Sweden, this has to be done by each balance responsible party 45 min before the hour of delivery at the latest [14].