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Impact of unpredictable renewables on gas-balancing design in Europe

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HIGHLIGHTS

- Intermittency is transferred from the electricity system to the gas system.
- Forecast errors increase intra-day and end-of-day balancing costs.
- Non-market based settlement inadequate to recover balancing costs.
- Market-based settlement fails to allocate costs to instigators of imbalances.

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ABSTRACT

The gas system in Europe is facing increasing unpredictability due to the interactions with the electricity generation system. Indeed, gas fired power plants make up an important back-up technology to deal with intermittency induced by wind-power integration. Therefore, the flexibility needs with respect to unpredictable power generation are actually transferred to the gas market. Applying the well-known electric power generation concepts of 'unit commitment' and 'dispatching' to the gas market, a hypothetical gas-transmission system has been modeled to verify, first, the physical impact of wind power forecasting errors on the gas system, and, second, its effect on the organization of gas-imbalance settlement for non-market-based and market-based design options. Increasing unpredictability leads to more expensive physical balancing of the gas system. These costs should be borne as much as possible by those effectively causing them. From a regulatory point of view in the European context, cost recovery by means of non-market-based settlement faces the problem of defining an appropriate cost-neutral penalty that covers the balancing costs and incentivizes shippers. Market-based settlement relates the variable imbalance tariffs to the actual system imbalance and thus any factor that strongly impacts on the system state like unpredictability. However, this mechanism raises imbalance-settlement tariffs for all unbalanced gas network users, even if the major source of unpredictability is a clearly identifiable shipper.

1. Introduction

The gas system and electricity-generation system are interacting due to the use of gas-fired power plants, but also more and more because these plants are used to balance the electricity system. This interaction is expected to further increase in the future. The gas system, then, has to deal with this changing context: gas is storable, but physical and organizational challenges remain present in the balancing of the gas network. This paper discusses this overlooked problem in the literature on gas regulation, which is of particular interest in Europe today, and even more so in the next decades, because the organization of gas balancing is still under much debate. The main research question is how this new kind of unpredictability in the gas system interacts with possible organizational designs of a gas-balancing mechanism in the European context. Towards this aim, the physical impact of balancing with gas is looked at in a conceptual case study that presupposes the balancing of wind-power output by gas-fired power, disregarding and thus excluding other balancing tools in the electricity-generation system. By using an operations research model, the physical impact on the gas system is simulated and the associated costs are calculated. Finally, these costs have to be passed on to unbalanced shippers. Note that the case study is conceptual and that the conclusions are therefore qualitative, and are not relating to a particular existing energy system.

The investigated problem basically originates in the large-scale introduction of renewable-energy sources (RESs) in the electricity system. The roll-out of these RES affects the electricity-generation system [1] and required grid [2], but also have an impact on the role of other energy carriers such as natural gas (which can accommodate this RES roll-out). Wind power has an intermittent character, meaning the output is variable and to some extent unpredictable [3]. Furthermore, wind power has zero marginal

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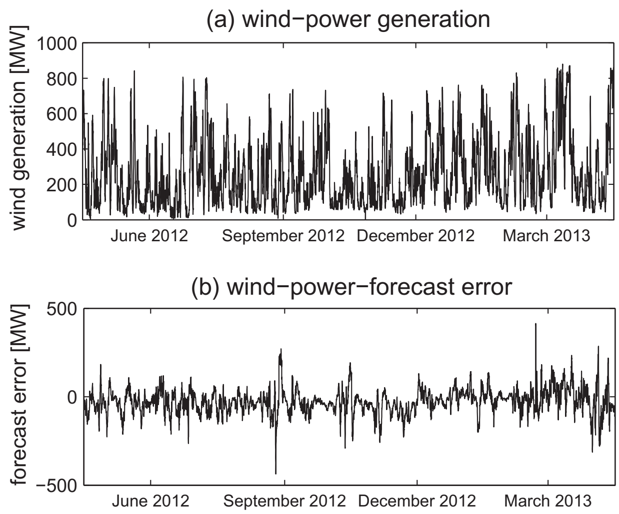

Fig. 1. (a) Wind-power output and (b) wind-power-forecast error, for the period May 1, 2012 – April 30, 2013, for Belgium. A positive forecast error indicates an overestimation (forecast higher than actual value), whereas a negative error indicates an underestimation (forecast lower than actual output). Data obtained from Elia [10].

costs and as such replaces other, dispatchable electric power plants in the dispatching order when generating [4,5]. Thus, electricity balancing tools are required to deal with this wind-power intermittency [1]. Possible balancing tools consist of pump-hydro storages, demand-side responsiveness and flexibly dispatchable conventional power plants, such as gas-fired electric power generation (GFPP). Lower investment cost, favorable CO_2-emission characteristics, flexible operability and a relatively short lead time between final investment decision and actual operation of a plant make, e.g., open-cycle gas turbines (OCGT) and combined-cycle gas turbines (CCGT) attractive technology [6–9].[1] Current high fuel prices in Europe represent a downside of GFPP technology, but the worldwide development of shale gas and the LNG market may change this. Furthermore, the inclusion of CO_2 prices improves the relative fuel cost compared to, e.g., coal-fired electric power plants.

As an example, Fig. 1 shows the day-ahead forecast of wind power, together with the actual wind-power output for the year 2012 for the Belgian system, which has approximately 1000 MW installed wind-power capacity, to illustrate both the variable and unpredictable character.

When gas-fired power plants are used for balancing, the flexibility needs of the electricity-generation system are (partly) transferred to the gas system, imposing a need to allocate system-flexibility costs to the users thereof. Gas-Balancing-responsible shippers can rely on the *ex-post* balancing services provided by the gas TSO (transmission-system operator) or they can take measures to contract *ex-ante* flexibility services [11]. Pivotal to this choice are the gas-balancing rules that have to allocate the system costs to the unbalanced party, on the one hand; and incentivize shippers to balance beforehand, on the other hand. The addition of wind power and its interaction with mainly GFPPs changes the gas-demand characteristics. It will be demonstrated that some current balancing-mechanism designs become impractical (and on the long term perhaps unsustainable) to deal with this changing gas demand.

[1] Open-cycle gas turbines (OCGTs) are actually providing more dispatching flexibility as that technology allows even higher ramping rates than CCGTs. However, for the conceptual analysis in this paper, CCGTs have been chosen arbitrarily as the considered GFPP technology.

The role of gas and wind in the power-generation mix has been underlined many times in the literature on the operation of electricity systems. Delarue et al. [12] have demonstrated that for electricity systems with a diverse generation mix, wind power mainly interacts with GFPPs. The Spanish electricity system with its massive amount of wind power has been shown to strongly rely on CCGT-related flexibility to deal with rising electricity-generation volatility [13]. The expected impact of large-scale wind-power integration on the UK gas network has been found to come down to more CCGTs operated in a flexible way and results in substantial line-pack swings, more gas-compression-power consumption and more overall gas use for electric power generation [14]. Furthermore, concerns are raised in that study by Qadrdan et al. [14] regarding very rapid depletion of the line-pack buffer if the "wrong" circumstances occur: a combination of low wind-power output, peak electrical gas demand and peak non-electrical gas demand. In a way, massive wind power is crowding out other electricity-generation technologies in favor of more flexible gas in terms of new capacity added (MW). Moreover, long stretches of cold weather, and thus high heating demand, often coincide with periods of low wind speeds. The effective number of operating hours of CCGTs, and thus the number of MWh produced per year, on the other hand, is said to rise by some studies, e.g., [8], whereas other studies argue the effective running hours of CCGTs, or GFPPs in general, will go down, e.g., [9]. Nevertheless, gas' qualification as "fuel of consequence" seems justified.

Concerns about the changing interactions between gas and electricity have also been raised before in the literature. Hallack [15] extensively discusses the changing needs of the gas network imposed by the new demand characteristics of increasing gas-fired electric power. In the new gas market, short-term flexibility, exchangeability and storability (for short periods) are the keywords and the regulatory framework for gas-infrastructure development has to respond to these needs. The French regulator also has raised concerns about the surge of GFPPs, especially in the field of daily balancing of the gas loads [16,17]. Indeed, the balancing of gas supply and demand on an hourly and daily basis becomes more challenging because the flexible dispatching of GFPPs coincides with strongly varying gas needs: when ramping up a CCGT, gas withdrawal soars instantly, whereas the ramping down requires gas flows to drop almost instantly. Evidently, the management of pressure in the pipelines can deliver the needed flexibility. Yet, pipeline-based flexibility is limited in volume and can only be used for short-term storage [11]. The deployment of line-pack flexibility is not limited to a specific kind of gas demand, but evidence from the UK suggests that flexible CCGTs cause higher swings in the line pack, defined as the amplitude between the maximal and minimal line-pack level over a gas day, than the residential sector [11,18,19]. This was not perceived as very troublesome because the share of electric power generation in the European gas demand has been relatively low. Germany, Italy and Spain, however, show a remarkable growth of gas consumption in the electric power sector over the last decade [20,21]. Although smaller in absolute numbers, a similar trend can be observed in the other European countries as well, the exception being the UK, which remained more or less stable because its "dash for gas" already started in the late 1980s and early 1990s [22]. Moreover, power generation is projected to remain the main driver of growth in future (European) gas demand [6,7]. Consequently, the short-term gas-flexibility needs of the electric power sector will become a significant issue.

The regulation of gas balancing has mostly been studied in the industry literature in Europe. The regulators have published viewpoint papers, consultation papers and framework guidelines on how to organize settlement of imbalances [23–28]. The transmission-system operators and shippers have also contributed to the