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Integrated Market for Electricity and Natural Gas

an integrated market for electricity and natural gas systems with stochastic power producers

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INTRODUCTION

In energy systems with high shares of weather-driven renewable power sources, gas-fired power plants can serve as a back-up technology to ensure security of supply and provide short-term flexibility. Therefore, a tighter coordination between electricity and natural gas networks is foreseen. This paper examines different levels of coordination in terms of system integration and time coupling of trading floors.

Natural gas is considered an efficient and clean fuel that will have a key role in the future energy system. Older coal and nuclear power plants are gradually decommissioned and replaced by gas-fired power plants (GFPPs) and renewable sources of energy. GFPPs are a well-suited flexible component for the energy system that can support other flexible sources in the power system (e.g., hydro power) but, most importantly, enhance the link with the natural gas system and the opportunity to exploit its available flexibility.

In the existing setup, the main inefficiencies stem from the imperfect coordination between the trading floors, as well as between the markets for electricity and natural gas. Acknowledging the necessity for an improved coordination between electricity and natural gas short-term markets with high penetration of stochastic production, a coupled clearing model is proposed that anticipates future balancing needs and optimally dispatches the integrated energy system.

METHOD

1. Three market-clearing models are provided, ranging from the current decoupled and deterministic setups to the proposed coupled and stochastic approach. The aim is to identify and address the efficiency improvement by considering a coordinated framework between systems and trading floors.

2. A market design that couples the electricity and natural gas markets in the day-ahead and balancing stages, while considering the uncertainty introduced by stochastic power producers, is proposed. Moreover, an effective pricing scheme is developed and the relation of GFPPs' operating cost with the outcomes of the natural gas market is taken into account.

3. A tractable and linearized natural gas model with line pack is considered, while we show that this approach takes advantage of the flexibility of the natural gas network to facilitate the integration of renewables. Furthermore, we quantify and highlight the increased performance of the model in our analysis.

RESULTS AND FINDINGS

This paper proposes a co-optimization model for integrated electricity and natural gas systems that efficiently takes into account uncertain power supply. It follows a linearization approach to approximate the dynamics of the natural gas system that yields a tractable mixed-integer linear programming (MILP) model and considers the possibility to store gas in the pipelines of the natural gas network (i.e., linepack), which is of significant importance in short-term operations. The combination of the aforementioned model properties results in increasing operational flexibility and in improved allocation of gas resources in the network.

Comparison of market-clearing models and the effect of coordination parameters

It is observed that Stoch-Coup achieves the lowest expected cost in both cases of 40% and 50% wind power penetration by efficiently accommodating the large shares of renewable power production. This model decides the optimal day-ahead dispatch to account for wind power uncertainty which results in a higher day-ahead cost but lower expected balancing cost, while the share of GFPPs that are efficient balancing producers also increases compared to deterministic models Seq-Coup and Seq-Dec.

The Stoch-Coup model handles uncertainty more efficiently than the deterministic ones and this is observed by the greater decrease in expected cost it accomplishes when increasing the wind power penetration level from 40% to 50%. The wind power scenarios are normalized and then multiplied by the wind farm capacity; thus a higher penetration results in scenarios with higher mean and variance.

The spatial allocation of natural gas in the system plays an important role for short-term adequacy and available flexibility in view of the ability to store gas in the pipelines. For the cases of natural gas price mis-estimation, it can be noticed that there might be different effects on the total expected cost depending on wind power penetration level. The day-ahead cost increases when the natural gas price is mis-estimated compared to Seq-Dec that utilizes the actual natural gas price from Seq-Coup.

The benefits and effects of linepack

The linepack decreases throughout the scheduling horizon when the initial level is higher than the final condition and the storage facility is not utilized at the day-ahead stage. This rate of decrease depends on the residential natural gas demand profile, while there are a couple of periods that the linepack is charged when the residential demand is relatively low.

On the other hand, the linepack is increased when its initial value is lower at the beginning of the scheduling horizon. The highest rate of increase is observed when the residential natural gas demand is low during the first hours of the day.

In both cases, the linepack is decreased below the final hour threshold during the hours of peak residential demand to avoid supplying natural gas by the expensive natural gas producer.

The GFPPs are serving as a flexible demand component for the natural gas system, by either increasing or decreasing their fuel consumption, in favor of a cost-effective operation of the integrated energy system.

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