STRATEGIC BEHAVIOUR IN FLEXIBILITY MARKETS: NEW GAMES AND SEQUENCING OPTIONS

Ellen Beckstedde, KU Leuven/Vlerick Business School, +32 16 24 88 29, ellen.beckstedde@vlerick.com
Leonardo Meeus, Vlerick Business School/Florence School of Regulation, + 32 22 25 41 29, leonardo.meeus@vlerick.com
Erik Delarue, KU Leuven/EnergyVille, +32 16 32 25 21, erik.delarue@kuleuven.be

Overview

With the uptake of distributed energy resources, the European energy scene experienced significant changes over the last decades. In the coming years, a further transformation is expected due to the deployment of new flexible network users that come from the electrification of the transport, building and industry sector. As most of these new grid users will be connected to the distribution network, Distribution System Operators (DSOs) face a major network integration challenge. A recent study by Eurelectric and E.DSO shows that DSOs in Europe will in total need to invest 375-425 €bn in their networks between 2020 and 2030 (Eurelectric, et al., 2020). Luckily, due to their flexible characteristics, these new network users do not only contribute to this DSO challenge, but could also be part of the solution. For this reason, DSOs are expected from the Clean Energy Package to procure flexibility in a market-based way when it is cheaper than expanding their distribution network. Different pilots and research projects on flexibility markets do already exists today, but overall, the integration of these flexibility markets in the existing sequence of European electricity markets remains an important open issue (Meeus, 2020).

We were inspired by two streams of literature to contribute to this discussion. The first stream relates to market sequencing options. These options are often referred to as alternative TSO-DSO coordination schemes because they imply different levels of cooperation between the Transmission System Operator (TSO) and DSOs. TSOs are typically responsible to balance the system (via balancing markets) and to manage congestion in transmission networks (via redispatch markets), while DSOs are responsible to manage the congestion in distribution networks (via flexibility markets). Different sequencing options therefore consider the separate or (partly) integrated organisation of these markets. CEDEC et al. (2019) describe the common vision by TSO and DSO associations, and publications by academics, such as Gerard et al. (2019), Vicente-Pastor et al. (2019) and Le Cadre et al. (2019), have started to analyse the performance of different sequencing options. Several authors already referred to the strategic behaviour of market parties, but it has not yet been modelled extensively. The main contribution of this paper is therefore to model the strategic behaviour of market parties under the alternative sequencing options. For our modelling approach, we were inspired by a second stream of literature on the inc-dec game. This game was first discovered between inter-zonal electricity markets and intra-zonal congestion management at transmission level in California (Stoft, 1998; Harvey & Hogan, 2001). Several authors continued to work on inc-dec games in the context of transmission networks. Dijk & Willems (2011), Holmberg & Lazarczyk (2015) and Hirth & Schlecht (2019) examine the inefficient aspect of counter-trading and the cost of the inc-dec game to argue for nodal pricing. Sarfati et al. (2019) formulate a mathematical model that simulates this. The literature on the inc-dec game does not yet consider the recent developments in distribution networks with flexibility markets, which is the focus of this paper.

In this paper, we combine the literature on market sequencing options and the literature on the inc-dec game to examine the integration of flexibility markets in the sequence of electricity markets while considering the presence of strategic market players. The paper is structured in two parts. First, we explain the modelling approach. Second, we apply this approach to a numerical example. We identify old and new games that can be triggered by flexibility markets, and compare the performance of the sequencing options under power system and market structure sensitivity.

Methods

A schematic overview of the relation between the sequencing options and different market players can be found in Figure 1. The following four market sequencing options are analysed: (1) WNC or a nodal wholesale market that considers transmission and distribution network constraints during the market clearing; (2) WIR or a zonal wholesale market that does not consider network constraints and is followed by a redispatch market where transmission and distribution constraints are managed in a coordinated way; (3) WFRB or a zonal wholesale market followed by separate flexibility, redispatch and balancing markets in which congestion at distribution level is treated before congestion at transmission level; and (4) WRFB or a zonal wholesale market followed by separate redispatch, flexibility and balancing markets in which congestion at transmission level is managed before congestion at distribution level.

For each sequencing option, we model perfect competition as the reference case and compare this to a situation where a strategic market party is the first mover in the market. This implies that the market parties, here represented by Balancing Responsible Parties (BRPs), can behave competitively or strategically. We use a Monte Carlo simulation to randomly assign the power system generation units to the competitive and strategic BRP. The competitive BRP will offer all units to the different markets at their marginal cost. This behaviour can be captured by a single-level model and is solved as a Mixed Complementarity Problem (MCP). The strategic BRP act as a first mover and adjusts its price offer by anticipating the reaction of the competitive BRPs in the second stage. Depending on the sequencing option that is analysed with this bi-level model setup, the second stage will contain a different number of markets that are modelled separately. To find a solution, the bi-level problem is formulated as a Mathematical Program with Equilibrium Constraints (MPEC) as shown in Sarfati et al. (2018) and Ruiz et al (2012). In the WNC market sequence, the model is linearised and solved as a Mixed Integer Problem. In the options of WIR, WFRB and WRFB, the model is solved as a Mixed Integer Non Linear Problem of which the solutions are validated by using different starting points.

To sum up, there are eight versions of the model that are all analysed with a numerical example for a single timestep and the reference power system. The numerical example is illustrated in Figure 2 and builds further on the power system used by Hirth & Schlecht (2019). The examined network contains two transmission nodes N and S that are interconnected by a constrained transmission line. We added two distribution nodes that are connected to transmission node N: a constrained node n1 and an overdesigned node n2. Lastly, Figure 2 shows the location of the generator and load sources in the reference power system.

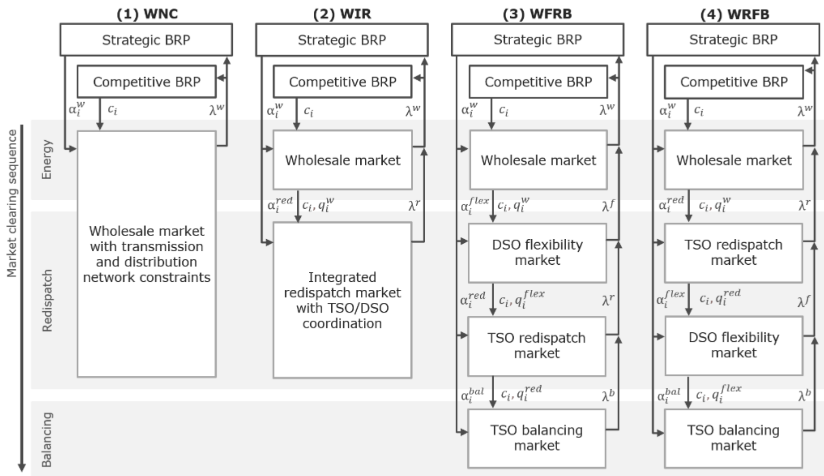

Figure 1: Schematic overview of the model

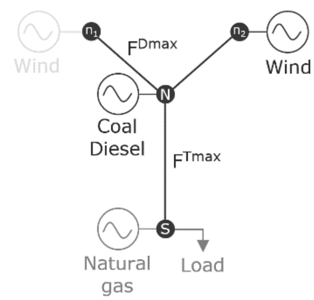

Figure 2: Numerical example

Results

The results are developed in three parts. First, we analyse the market outcome of the sequencing options under the reference power system and perfect competition. In this way, similarities and differences in the wholesale market and congestion management functioning of the four market sequencing options can be identified. Second, we examine the strategic behaviour of the BRP in each market sequencing option and illustrate old and new games that can be played. Old games involve the price setter game and the inc-dec game triggered by redispatch markets. New games concern (1) bidding strategies that arise because additional network constraints are treated in existing markets; (2) traditional inc-dec games that are now played between different sequential markets; and (3) new types of inc-dec game that are triggered by including flexibility procurement into the sequence of electricity markets. We also show how reservation can be used as a remedy for strategic behaviour and discuss the limitations of the model. Third, the performance of the sequencing options is examined by looking at power system sensitivity under perfect competition and market structure sensitivity under the reference power system.

Conclusions

In this paper we analysed four market sequencing options that consider network congestion at transmission and distribution level in the context of strategic market parties. We formulated a MCP and MPEC model to capture competitive and strategic behaviour in the different markets sequences. A reference power system was defined to illustrate the wholesale market and congestion management functioning of the sequencing options and to discover old and new games triggered by redispatch and flexibility markets. Finally, the performance of the four sequencing options was examined under power systems and market structure sensitivity.

In analogy with the inc-dec game triggered by redispatch markets, we find that flexibility markets can trigger new games among flexibility providers. Regulators that have the mandate to perform market oversight activities need to be aware of these new games to be able to detect them. We demonstrate that market power is an important issue to take into consideration when deciding on the integration of flexibility markets in the sequence of electricity markets. When comparing the sequencing options, we did not find a clear winner; their relative performance is very sensitive to the power system conditions and market structure.

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