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PHD THESIS

From vertical to horizontal structures: new optimization challenges in electricity markets

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This is a summary of the Ph.D. thesis of Jérôme De Boeck supervised by Bernard Fortz and defended on the 27th of January 2021 at the Free University of Brussels. The thesis is written in English and was finalist for the EURO Doctoral Dissertation Award 2022. It is available from the author upon request at Jerome.De.Boeck@ulb.be and from https://difusion.ulb.ac.be/vufind/Record/ULB-DIPOT:oai:dipot.ulb.ac.be:2013/318361/Holdings. This work provides an overview of several optimization problems related to the electricity supply chain and their evolution over the past years. Liberalization of electricity markets and new technologies are having a strong influence on how to organize electricity production and transmission. Many components of the electricity supply chain are shifting from vertical to horizontal decision mechanisms introducing new interactions. Previous computational methods used in electricity-related problems need to be updated to follow the evolution of real-life constraints.

One classical problem for a generation company (GC) is the Unit Commitment problem (UC) which consists of establishing an electricity production plan over a given time horizon to satisfy the electricity demand. When first considered, the price of electricity and the demands were relatively easy to estimate. This problem has been widely studied and solved using Mathematical Programming (MP) methods, mainly Mixed Integer Linear Programming (MILP). Today, the price of electricity can be relatively volatile due to the introduction of deregulated electricity markets in which several independent GCs compete in several different markets run by a Market Operator (MO). The MO settles the price of electricity based on bids proposed by the competing GCs as well as the quantities each of them is allowed to sell. When estimating profit, a GC cannot, therefore, consider solving only a UC problem. There is a need of integrating the market mechanism in the decision process of a GC when establishing a production plan. Traditional MILP formulations used for the UC must be redefined as bilevel formulations which are much more challenging to solve.

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Technology has also led to new conceptual organization in the electricity supply chain through Micro-Grids (MGs). A MG is composed of a group of power consumers who have their power generation units and optimize their internal electricity consumption. This concept is possible due to the increasing use of renewable energy sources and the increasing penetration of interconnected devices used in daily life. Still, because renewable energy sources are intermittent and storage devices are still not sufficiently efficient, MGs cannot consider being autonomous regarding electricity production. Therefore, MGs must have external power suppliers to ensure sufficient electricity supply. A GC trading electricity with a MG faces a lot of uncertainty regarding its demand because of the internal management of the MG over which a GC has no control. This situation asks again for new computational methods considering the interaction between different actors.

We also face increasing difficulties in electricity transmission regarding reliability. Optimization problems related to transmission networks have also been studied for a long time as the UC under simple hypotheses, namely a low number of power generators with a high capacity to which consumers are to be connected. As renewable energy production devices have a much more limited capacity than fossil energy sources, the number of production sites in a transmission network is increasing. The assignment of consumers to energy sources is more challenging due to the limited capacity of generators and the need for robustness in the distribution.

In this thesis, several optimization problems considering modern constraints related to the electricity supply chain are studied through MP. Several problems consider interactions between actors and are modeled through bilevel formulations. We illustrate how the difficulties introduced by the evolving context can lead to scalability issues but can also be used to derive properties of the models considered to derive new solving approaches. Efficient heuristic methods are obtained inspired by the exact formulations proposed, some of which apply to more general problems. An extensive analysis of the performance of the proposed solving methods is performed, as well as the negative impact of traditional hypotheses made in state-of-the-art solving methods when applying results in real-life situations.