Evaluation of European Gas Market Designs

The Entry-Exit System

The liberalization of the European gas markets started in the 1990s and lead to the current situation in which European transmission system operators (TSOs) typically operate under the so-called Entry-Exit system [1, 2, 3]. The timing of this system is as follows: The TSOs have to publish so-called technical capacities at every entry or exit point of the their network. Afterward, gas traders can book capacities that are bounded above by the corresponding technical capacity. The booking is a capacity right that ensures that the trader can inject (as an entry customer) or withdraw (as an exit customer) balanced amounts of gas up to the booked capacity. The latter process is called nomination and the TSOs have to be able to transport all possible nomination situation as they are (via the bookings) conformal to the published technical capacities.

Mathematical Models and Challenges

The current entry-exit system can be addressed by mathematical modeling in various ways. From the perspective of the evaluation of this market design one is faced with multilevel models that are made up of the following levels:

a) Computation of technical capacities by the TSO
b) Booking by gas traders
c) Nomination by gas traders
d) Transport by the TSO

For the ease of presentation we refrained from discussing secondary intra-day markets [4, 5].

The first mathematical challenge is the robustness the TSO has to address when computing the technical capacities in level a): All balanced nominations that are restricted by the bookings that themselves have to be in line with the TSO's technical capacities have to transportable by the TSO. Feasibility of transport depends on the physical model of gas flow and of the chosen models of technical entities of gas transport networks like compressor and control valve stations, filters, measurement devices, etc. The former is typically modeled by systems of nonlinear and hyperbolic partial differential equations (the Euler equations, cf., e.g., [6]) on a graph. The latter are mainly modeled by algebraic but highly nonlinear discrete-continuous equality and inequality systems [7, 8]. Assuming the TSO's goal of cost-minimal transport of nominations, the levels a) and d) alone lead to adjustable robust mixed-integer nonlinear optimization problems that are subject to hyperbolic partial differential equations on a graph.

Since the acting agents (TSO and gas traders) in this market game typically have different objectives one is readily confronted with multilevel optimization or complementarity problems in levels b) and c) that are intermediate levels in the overall equilibrium problem.

Further Directions of Research

Although the mathematical model described so far is extremely challenging and far beyond the border of what can be solved with the current state of mathematical theory and algorithmic technology, there are still a lot of possible extensions of this setting. One possible extension is the consideration of uncertainty in the given setting: cf., e.g. [9, 10]. Typically, the exact gas demand is unknown before booking and nomination. Thus, both stochastic and robust optimization techniques may be employed to address this issue.

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