Air Separation with Cryogenic Energy Storage: Optimal Scheduling Considering Electric Energy and Reserve Market Participation

Cryogenic energy storage (CES) is a new technology that is being pioneered in the UK (Harrabin, 2012). The idea of CES is to store energy in the form of liquid gas. When energy is needed at a later time, the liquid gas is pumped to high pressure and evaporated; the high-pressure gas can then be used to drive a turbine to generate electricity. Interestingly, although CES on an industrial scale is a relatively new approach, the technology used for CES is well-known and essentially part of every air separation plant that utilizes cryogenic separation. This raises the question of whether an air separation plant can benefit from its CES capability by, for example, storing energy when the electricity price is low and recovering energy for its own use or to sell it back to the grid when the price is high. Moreover, the ability of such a plant to generate power creates the new opportunity of participating in reserve markets.

In this work, we investigate the potential operational benefits of adding CES to an existing air separation plant. Based on the scheduling model proposed by Mitra et al. (2012), we develop a mixed-integer linear programming (MILP) model that integrates the air separation plant and the CES system, while considering participation in the day-ahead energy market as well as the operating reserve market.

When participating in the reserve market, we sell power generation capacity that can be dispatched when unplanned power generation is required in order to balance real-time electricity supply and demand. This is an intrinsically uncertain process since we do not know in advance when reserve will actually be needed. This means that if we sell reserve capacity for a certain period of time, we have to guarantee that we can dispatch the agreed amount of power at any time during that period of time. To consider this uncertainty, we apply a Robust Optimization approach in which the concept of the "budget of uncertainty" (Bertsimas & Sim, 2004) is used to control the level of conservatism.

We apply the proposed framework to a real-world industrial case study provided by Praxair, which leads to an MILP with up to 20,000 binary variables, 180,000 continuous variables and 110,000 constraints. Despite the large size of the problem, the MILP can be solved with modest computational effort (within minutes to 0.1 % integrality gap). The results show that adding a CES system to an existing air separation plant can significantly reduce the operating costs, particularly when we also consider the interaction with the reserve market.

References

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