EXPANSION PLANNING IN INTEGRATED POWER & HYDROGEN SYSTEMS

Thomas Florian KLATZER[1](*), Udo BACHHIESL[1], Sonja WOGRIN[1]

Introduction

To tackle the climate crisis, the European Union committed to achieving climate neutrality by 2050 with the intermediate target of reducing CO2 emissions by 55% by 2030 [1]. Reaching these ambitious targets requires enormous expansion of variable renewable energy (VRE) sources, power systems, and holistic integration of today's stand-alone energy systems. In 2020, the EU presented a hydrogen strategy aiming to establish 6 GW of electrolyzer units by 2024 and 40 GW by 2030 [2]. For the bulk transport of hydrogen the natural gas transmission system is considered as a promising option [3]. However, current regulations allow for hydrogen blending rates of 10% at most [4], [5] (due to end-appliances). This raises questions about the effects hydrogen might have on power systems, ideal siting of electrolyzer units, power transmission versus pipeline transmission expansion planning etc. To quantify resulting effects we model a stylized integrated power and gas system using an extended version of the Low-carbon Generation Optimization (LEGO) model [6] which is available on GitHub for open source download (base version) [7].

Methodology

LEGO is a mixed integer quadratically constrained optimization program with the objective of minimizing total system costs (operation and investment). Its modular structure (Figure 1) allows to choose from individual blocks, e.g. enabling generation and/or transmission expansion planning, unit commitment, modeling a single node problem versus a network problem (with AC- or DC-OPF), considering policy constraints etc. Recently, parts of the hydrogen sector have been implemented, starting with electrolyzer units and hydrogen demand per sector, e.g. transport [6].

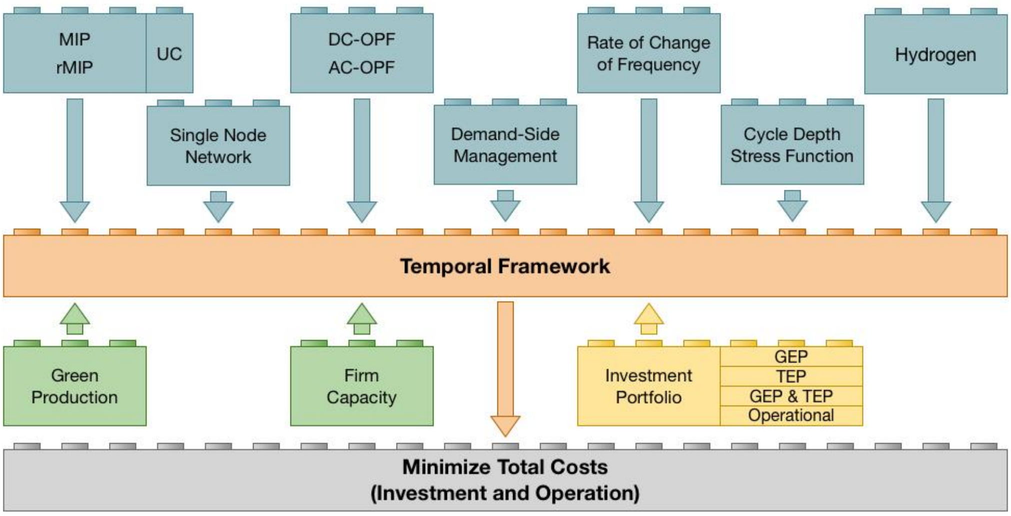

Figure 1: Structure of the LEGO model.

For this paper we implement a stylized high-pressure gas transmission network with a maximum operating pressure (MOP) of 90 bars. The system is composed of nine gas nodes and two gas wells (GWs). Gas flow is based on the steady-state general flow equation (1). Therein, $f_{k,ij}|f_{k,ij}|$ represents the squared gas flow and its direction per time step k, R_{ij} condenses pipeline and gas parameters

[1] Institute of Electricity Economics and Energy Innovation (IEE), Graz University of Technology, Inffeldgasse 18, Graz, +43 316 873-7908, thomas.klatzer@tugraz.at, https://www.tugraz.at/institute/iee/institut/team/klatzer-thomas/

including a pipeline friction factor, and $\left(p_{k,i}^2 - p_{k,j}^2\right)$ is the pressure difference between start and end node. Since this formulation is highly non-linear and non-convex we utilize piecewise linearization as suggested by [8], and substitute (1) with (2). Therein, A_{seg} and B_{seg} represent slope and intersect of the linear flow segment, $\left(\pi_{k,i} - \pi_{k,j}\right)$ represents the squared pressure difference, $\rho_{k,ij}$ is a slack variable, and $\delta_{k,ij,seg}$ is a binary variable to select a single flow segment.

$$f_{k,ij}\left|f_{k,ij}\right| = R_{ij}\left(p_{k,i}^2 - p_{k,j}^2\right) \qquad \forall\, k, ij \qquad (1)$$

$$\rho_{k,ij} + \sum_{seg}\left(A_{seg}\, f_{k,ij,seg} + B_{seg}\, \delta_{k,ij,seg}\right) = R_{ij}\left(\pi_{k,i} - \pi_{k,j}\right) \qquad \forall\, k, ij \qquad (2)$$

The power and gas system are coupled via closed-cycle gas turbines (CCGTs), open-cycle gas turbines (OCGTs), and electrolyzer units, while solar, wind, and battery energy storage systems (BESSs) complete the investment portfolio. Hydrogen production is limited by the amount of renewable power for all time periods. This ensures production of green hydrogen.

Preliminary results

In our base case study, we provide the model with the highest degree of freedom in terms of investment options and policy constraints, thus resulting in cost optimal investment and operational decisions (2035 M€). However, we find that the model does not built any electrolyzer units. Gas demand is solely covered by natural gas. If we enforce at least one percent of total gas demand to be covered by hydrogen, the model opts to install 90 MW of electrolyzers, resulting in 1.44% actual hydrogen production (2037 M€). If we enforce a minimum hydrogen share of 6.5%, total costs increase by 22 M€ (+1.1%) compared to the base case. Actual hydrogen production is 9.54% which is within the system's limit of 10%. Corresponding levelized cost of hydrogen (LCOH) is 0.054 €/Sm^3 or 0.600 €/kg. However, preliminary results show that LCOH increases for blend rates between 1% to 6.5%, while at a hypothetical blend rate of 100% LCOH is 0.037 €/Sm^3 or 0.412 €/kg.

References

[1] European Commission, "Regulation (EU) 2021/1119 of the european parliament and of the council establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')," *Off. J. Eur. Union*, vol. 2021, no. June, p. 17, 2021, [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119.

[2] European Commission, "A hydrogen strategy for a climate-neutral Europe," 2020. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

[3] J. Jens, A. Wang, K. van der Leun, D. Peters, and M. Buseman, "Extending the European Hydrogen Backbone," no. April, p. 32, 2021, [Online]. Available: https://transparency.entsog.eu/.

[4] IEA, "Limits on hydrogen blending in natural gas networks," 2018. https://www.iea.org/data-and-statistics/charts/limits-on-hydrogen-blending-in-natural-gas-networks-2018.

[5] Gas Connect Austria GmbH, "10 percent hydrogen share in natural gas grid," 2021. https://www.gasconnect.at/en/news/news-press/news/news/detail/News/neue-oevgw-richtlinie-10-prozent-wasserstoffanteil-im-gasnetz-ab-sofort-moeglich.

[6] S. Wogrin, D. A. Tejada-Arango, U. Bachhiesl, and B. F. Hobbs, "The full Low-carbon Expansion Generation Optimization (LEGO) model," 2021. [Online]. Available: http://arxiv.org/abs/2109.01368.

[7] S. Wogrin and D. Tejada-Arango, "LEGO on GitHub," 2021. https://github.com/wogrin/LEGO.

[8] Y. Zhang, Y. Hu, J. Ma, and Z. Bie, "A mixed-integer linear programming approach to security-constrained co-optimization expansion planning of natural gas and electricity transmission systems," *IEEE Trans. Power Syst.*, vol. 33, no. 6, pp. 6368–6378, 2018, doi: 10.1109/TPWRS.2018.2832192.