Synthetic models of distribution gas networks in low-carbon energy systems

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Summary

Gas networks are crucial assets in today's energy supply chain and are currently playing a key complementary role in the on-going decarbonization of energy systems. On the one hand, gas infrastructures are excellent candidates to provide strategic flexibility and reliability to future energy systems based on variable renewable sources of energy. On the other hand, switching from fossil natural gas to renewable or low-carbon gases is an unavoidable condition to keep the infrastructure running.

Increasing attention is therefore being devoted by policymakers, industrial players and academics, to the deployment of "green" gases in existing gas grids. Hydrogen and biomethane constitute the most promising options for an affordable decarbonization of the gas sector. Their integration into the grids comes with challenging technical and operational issues, as well as with opportunities of cross-sectorial couplings with, for example, the power grid.

The distributed injection of alternative gases – especially hydrogen – in pure form or blended with natural gas, affects the system hydraulics, changes the thermophysical properties of the transported fuel and raises concerns of safety at the end-users' appliances and of material compatibility within the infrastructure. On the other hand, significant benefits may derive by the deployment of low-carbon gases in the context of multi-energy systems where the electrical and gas grids interact through coupling technologies like power-to-gas.

Extensive research is therefore being carried out to assess the behaviour of gas grids in presence of distributed injections of alternative fuels, verify the compliance with gas quality prescriptions and hydraulic limits (e.g., pressures and velocities), and test new management schemes for both gas networks and integrated electricity and gas grids.

Most of the simulation studies, however, derive their results from only one or a limited number of network models. The findings of these works are therefore affected by a substantial case-specificity, which partially limits their validity and prevents their generalisation to other case studies.

To overcome this limitation, the present work proposes a tool for the synthetic generation of statistically similar gas network models, readily deployable for simulation applications at distribution-level systems. The main purpose of the tool is enabling the execution of simulative experiments over several (virtually infinite) case studies, with evident benefits in terms of validity and extendibility of the results. Attention is given to both topological and technical realism of the synthetic network models.

A topological approach supported by complex networks and system theoretical tools is undertaken to provide a structural characterization of gas grids, described with a graph-based representation. Structural information is therefore deployed to calibrate and validate a probabilistic generator of synthetic topologies, capable of delivering complex network structures with multiple pressure tiers. Network models are subsequently finalized by assigning technical specifications. This is addressed by means of a custom technical designer performing the correct and realistic sizing of distribution systems according to arbitrary design parameters.

The tool proves to successfully generate thousands of finished models of synthetic networks. A subset of synthetic grids is therefore deployed to study the effect of injecting hydrogen in distribution gas networks. Increasing penetrations of hydrogen are considered, and the impacts on the system hydraulics and gas quality are derived statistically.

The tool effectively enables a novel methodology for network simulations and offers a powerful support to studies with a systematic and generalized approach. Further perspective applications look promising and will contribute to a broader assessments of gas grids in low-carbon and integrated energy environments.