TIMELY RESOLVED NATURAL GAS GRID SIMULATION CONSIDERING HYDROGEN FEED-IN FROM VOLATILE RENEWABLE ENERGY SOURCES

Matthias Greiml[1], Nicolas Wolf Williams[1], Thomas Kienberger[1]

Content

The Austrian government aims to achieve 5 TWh of green gases (hydrogen, biomethane and synthetic natural gas from renewable electricity) by 2030 [1] . The amount of hydrogen being fed into the natural gas grid must comply with ÖVGW guideline *G B210*, which currently allows for a ten percent hydrogen admixture [2]. Feeding hydrogen from volatile renewable energy sources into the natural gas grid might cause timely fluctuations of the gross caloric value (GCV).

As part of a cooperation with the Large Engines Competence Center (*LEC GmbH*) in Graz, the *Chair of Energy Network Technology* at the Montanuniversitaet Leoben aims to determine in cooperation with *Energienetze Steiermark* to what extend volatile green hydrogen injection can cause GCV fluctuations in natural gas grids. A new methodology has to be developed to simulate timely resolved GCV fluctuations. By means of the investigation of various different scenarios, we investigate the impact of an H_2-content of up to 50 % in the natural gas grid.

The aim of this paper is to show the developed simulation methodology as well as simulation results, based on the use case of Styria.

Methodology

Future hydrogen generation may depend on the availability of renewable energies. Especially wind and photovoltaic are volatile renewable energy sources, which require a flexible and volatile mode of operation for an electrolysis. A flexible and volatile electrolysis operation would cause volatile hydrogen feed-in into the natural gas grid.

Currently, there is no methodology available to track hydrogen feed-in into natural gas pipelines and assess timely and spatially resolved GCV fluctuations. Static steady-state load-flow calculation tools are available, but no dependencies between different time steps are considered. Rüdiger's [3] approach adopts the node potential analysis for power grids in combination with Darcy's equation (refer to Equation 1) to determine gas load-flows [3]. The gas grid is depicted as a node-edge model. An iterative process, using Newton-Raphson solver determines load-flows and pressure levels in the natural gas grid for each node.

$$\Delta \mathrm{p} = \lambda \cdot \frac{8 \cdot \rho \cdot \mathrm{l} \cdot \dot{\mathrm{V}}^2}{\mathrm{d}^5 \cdot \pi^2} \tag{1}$$

This approach is extended by a batch tracking & tracing concept (further referred to as batch tracking), allowing the consideration of spatially and timely resolved distribution of gases (as natural gas - hydrogen mixtures) in the gas grid. The introduced semi-dynamic batch tracking method uses results from Rüdiger's steady-state algorithm to determine the distance travelled of gas bubbles, being fed into the natural gas grid. Gas bubbles are further referred to as batches, representing a gas fraction (hydrogen, natural gas or mixture) with specific properties (GCV, density). This iterative calculation process is shown in Figure 1, and will be explained following.

Load flow calculation

Rüdiger's algorithm requires the GCV of a gas mixture to determine a volume flow based on the nodes consumption or generation. An initial guess is necessary for the first iteration loop. This initial guess can be based for example on GCV results from the previous time step. Based on nodes demand or

---

[1] University of Leoben, Chair of Energy Network Technology, Franz-Josef-Straße 18, 8700 Leoben, +43 3842 402 5401, evt@unileoben.ac.at, evt.unileoben.ac.at

generation volume flow, Rüdiger's algorithm determinates volume flows between nodes and node pressures.

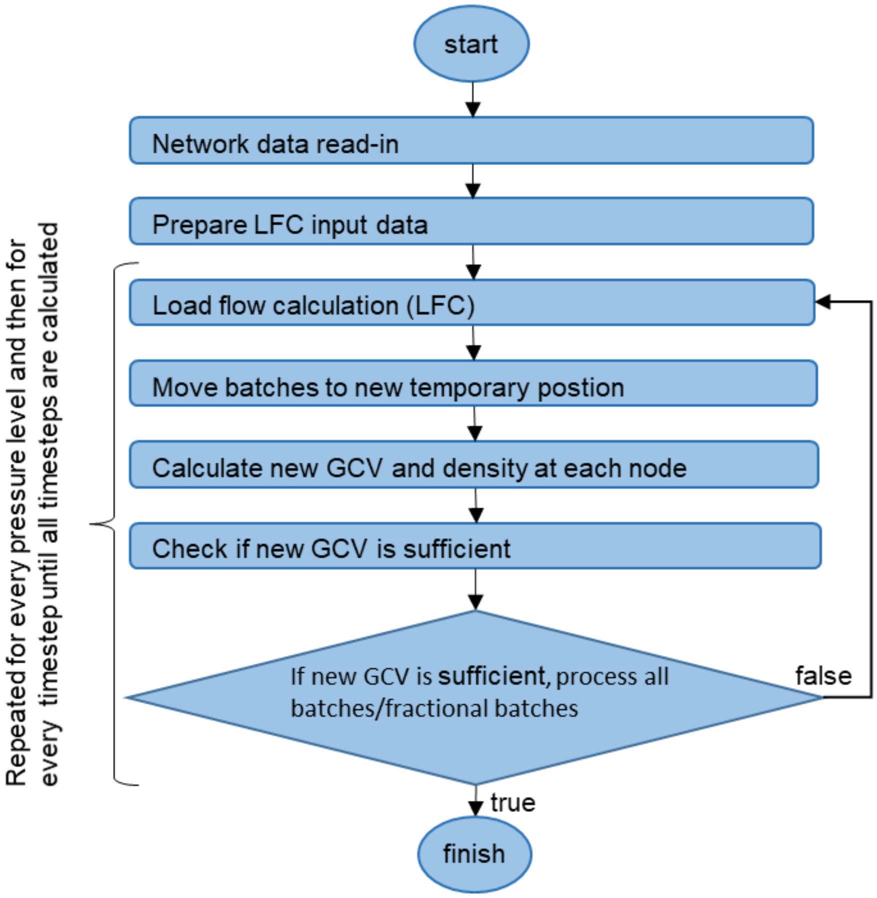

Figure 1: Graphic display of calculation procedure

Move batches to new temporary position & Calculate new GCV and density at each node

To model the flow of individual gases and the resulting time-resolved gas mixture at each node, a batch tracking method is implemented. As can be seen in Figure 2, the gases within the pipeline are characterised into individual batches with their respective density and gross calorific value from various origins. Equation 2 is used to determine the GCV of each node, depending on batches that reach or pass by the node within one time step.

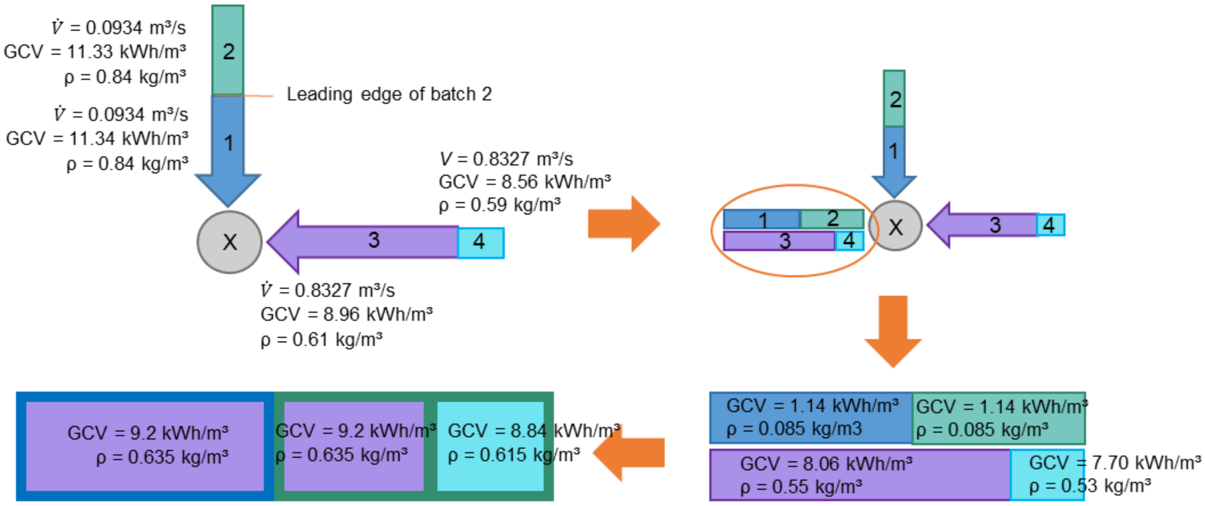

Figure 2: Example of batch tracking process

$$GCV_{node} = \sum \left(GCV_i \cdot \frac{Vol_{batch_i}}{Vol_{tot}} \right) \tag{2}$$

The batch volume $Vol_{batch,i}$ and volume total Vol_{tot} are calculated using the following Equations 3 and 4. The length of a batch is calculated by subtracting the leading edges position of the current batch by the leading edge position of the batch directly behind it. In the case where there were no batch directly behind the batch, the position of the node directly behind the batch is subtracted from the leading edge. The term "leading edge" refers to the point in a batch that is the furthest along the pipeline. Refer to Figure 2 for an example of a leading edge and the descript calculation procedure.

$$Vol_{batch} = l \cdot \pi \cdot r^2 \tag{3}$$

l … length [m]
r… radius of edge (pipe) [m]

$$Vol_{tot} = \sum (\dot{V_i} \cdot 60 \cdot t_{interval}) \tag{4}$$

$\dot{V_i}$ … volumetric flow rate [m³/s]
$t_{interval}$ … time interval for one time step [min]

To determine the distance that each batch travelled between specific nodes, the following Equation 5 is used. *Distance* represents the total distance travelled by the leading edge of a batch during one time step.

$$distance = \frac{\dot{V_i} \cdot 60 \cdot t_{interval}}{\pi \cdot r^2} \tag{5}$$

$\dot{V_i}$ … volumetric flow rate [m³/s]
$t_{interval}$ … time interval for one time step [min]
r … radius of edge (pipe) [m]

Check if new GCV is sufficient

The iteration shown in Figure 2 is carried out until the GCV at the nodes are sufficient, representing an abort condition. Sufficiency can be set by the user, depending on average GCV changes between two iteration steps.

Addressing various network / pressure levels

In case a network with more than one pressure level (e.g. more than one grid level) is assessed, the whole described calculation process must be carried out „bottom-up“ and then „top-down“ to determine the GCVs at each node. This procedure is necessary, since final GCV at lower network levels are depending on the GCV of gas supplied from higher pressure levels. At higher pressure levels volume flow generations or demands are not finally available, since they are dependend on the GCV of gas supplied to sub-networks. The „bottom-up“ calculation provides consumption data to higher pressure grids, whereas the „top-down“ calculation forwards GCVs to lower pressure grids. In case the initially guessed GCVs (to provide consumption data) differs from a user-set limit in comparison to the calculated GCV, the bottom-up and top-down calculation needs to be carried out repetitive.

Addressing changes in elevation of nodes

The presented model also takes into account the static pressure drops due to elevation change using a derivation of the barometric formula with the assumption that temperature is constant. Refer to Equation 6.

$$\triangle P = P_0 \cdot \exp\left(\frac{-M \cdot g \cdot h}{R \cdot T}\right) \tag{6}$$

P_0 … pressure of the pipeline [Pa]
M … molar mass of the gas [kg/mol]
h … height of the node relative to reference level [m]
R … gas constant [J/mol ∗ K]
T … operating temperature [K]

Scenario

In Figure 3, the high-level natural gas grid of Styria is depicted in a simplified way. Natural gas can be fed into the grid from north (node 2), east (node 15), and south (node 11). We assume that hydrogen can be generated by either photovoltaic driven electrolysis in the south near node 11 or by wind driven electrolysis in close proximity of node 14. Energienetze Steiermark provided properties of the natural gas grid as well as time-resolved consumer profiles. The hydrogen generation profile is based on real photovoltaic and wind generation data.

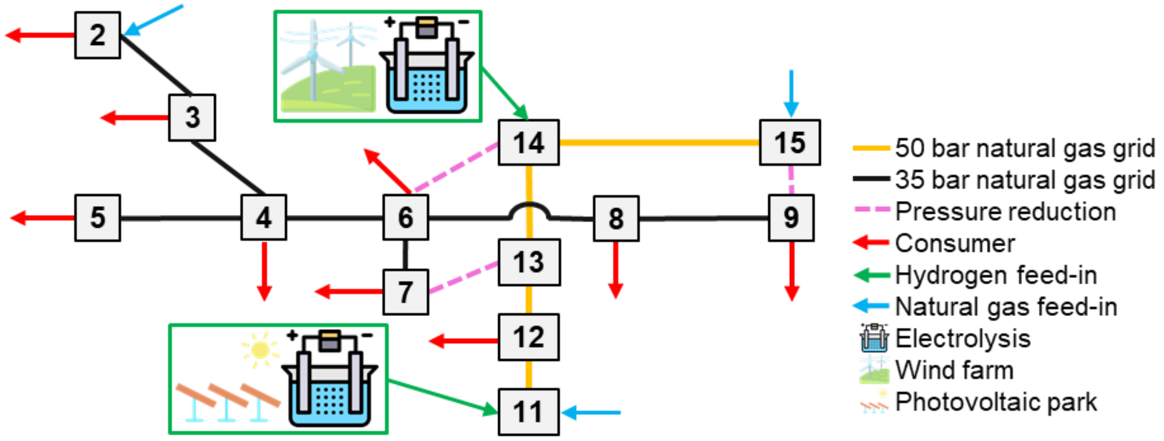

Figure 3: Depiction of considered grid section for simulation

Results

An excerpt of the time and spatially resolved GCV fluctuations can be seen in Figure 4. The displayed results are from January, therefore, photovoltaic generation is rather low (see high GCV at node 11 and 12). In contrast, the wind farm shows strong fluctuation in its generation, resulting in GCV fluctuations at node 14 and surrounding. It can be seen that the GCV fluctuations of node 6 follow the fluctuations of node 14 closely. In comparison node 5 is further away from node 14 compared to node 6. Therefore, it takes several time steps until the hydrogen - natural gas mixture reaches this node and causes GCV fluctuations. Node 8 is influenced by gas flows from both node 6 (hydrogen, natural gas mixture) and 9 (pure natural gas), resulting in a lower fluctuation than node 6. Due to the gas flows in the grid, certain nodes such as 2,3, 9 and 15 (not displayed in Figure 4) are not affected by GCV fluctuation, since no hydrogen flows to these specific nodes.

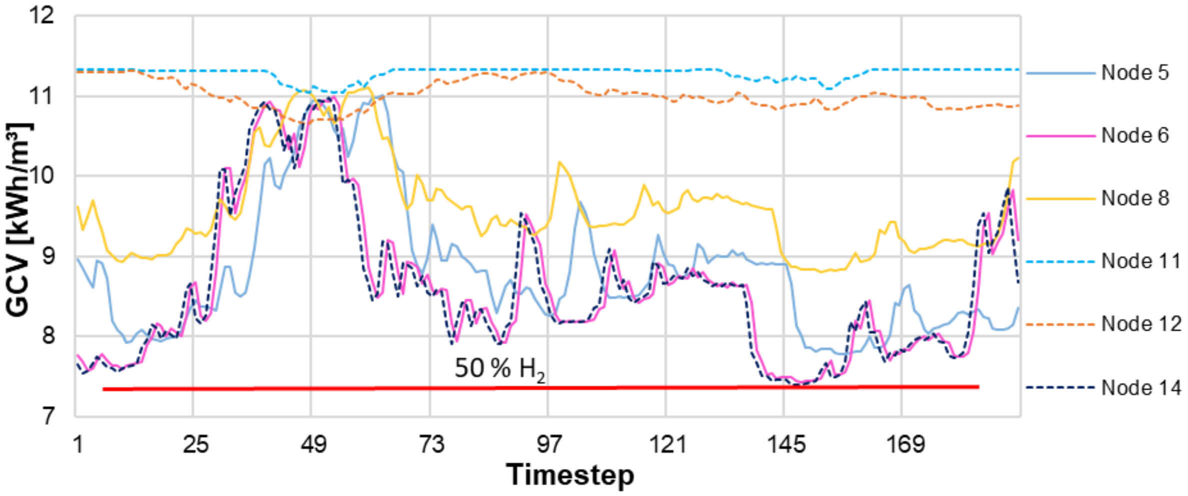

Figure 4: Example of spatial and time resolved GCV – Winter

In contrast to Figure 4 in Figure 5 results from summer are displayed. It can be seen that the amount of hydrogen generated from photovoltaic is significantly higher, resulting in lower GCV at nodes 11 and 12 near to the hydrogen injection node. Generally, the natural gas flows are similar, in terms of directions of flow, compared to winter. However, lower demands result in slower flow velocities, therefore increasing the number of time steps a node reacts to GCV fluctuations, as can be seen for example at node 5. It can be seen that the 50 % hydrogen limit is exceeded. This issue could be addressed either via smaller electrolysis or temporary storage. About twice as much hydrogen can be feed-into the natural gas grid in winter compared to summer, because of higher demand in winter, mainly due to gas for heating purpose demand.

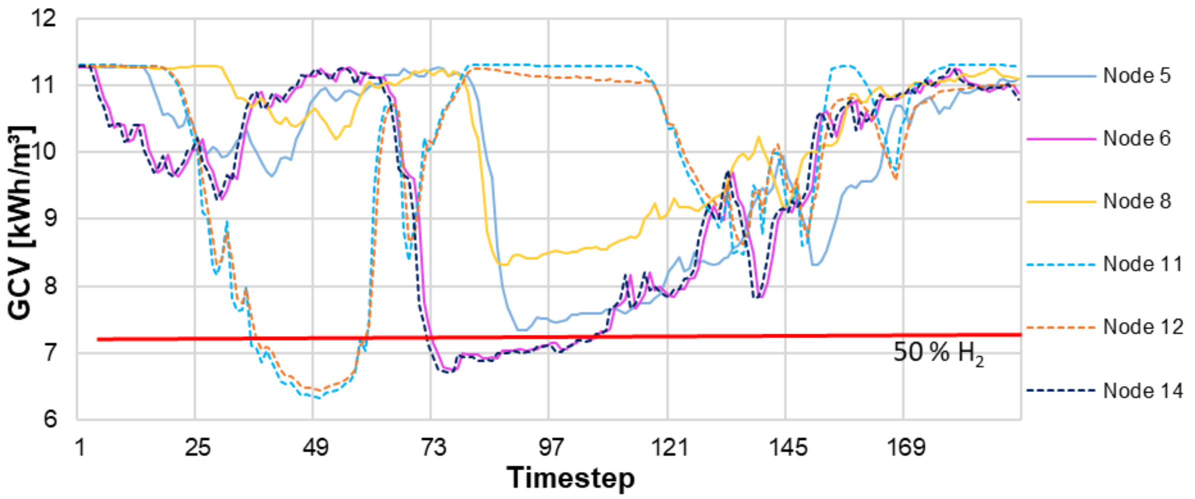

Figure 5: Example of spatial and time resolved GCV – Summer

Conclusion

Within this work, we discuss the effects of hydrogen admixture of up to 50 percent from volatile renewable energy sources into the natural gas grid. To determine timely and spatially fluctuations of GCVs, an existing steady-state natural gas load flow calculation is extended by a quasi-dynamic batch tracking concept. Based on real grid and consumption data provided by project partner *Energienetze Steiermark* the GCV fluctuations in summer and winter are assessed. Fluctuations of GCV in the grid are similar in summer and winter. However, since the consumption in summer is lower compared to winter less hydrogen can be feed-into the grid. The assessed nodes are affected differently by GCV fluctuations, depending on the direction of flows and location in the grid.

Funding

The authors would like to acknowledge the financial support of the "COMET - Competence Centres for Excellent Technologies" programme of the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and the Federal Ministry for Digital and Economic Affairs (BMDW) and the provinces of Styria, Tyrol and Vienna for the COMET Centre (K1) LEC EvoLET. The COMET programme is managed by the Austrian Research Promotion Agency (FFG).

References

[1] Bundeskanzleramt, Ed., “Aus Verantwortung für Österreich: Regierungsprogramm 2020 - 2024,” Bundeskanzleramt, Wien, 2020. Accessed: Nov. 11 2021. [Online]. Available: https://www.bundeskanzleramt.gv.at/dam/jcr:7b9e6755-2115-440c-b2ec-cbf64a931aa8/RegProgramm-lang.pdf
[2] ÖVGW, *Mehr Grünes Gas im Gasnetz.* [Online]. Available: https://www.ovgw.at/aktuell/
[3] J. Rüdiger, “Enhancements of the numerical simulation algorithm for natural gas networks based on node potential analysis,” *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 13119–13124, 2020, doi: 10.1016/j.ifacol.2020.12.2282.