Influence of Excess Power Utilization in Power-to-Heat Units on an Integrated Energy System with 100 % Renewables

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Introduction and Previous Work

Reducing CO_2 emissions to limit the effects of climate change is one of the biggest challenges of today's society which will lead to a significant change of the architecture of our energy system.

To examine the configuration of the future integrated energy system of Germany, many studies have optimized the system using quasi-stationary models which neglect dynamic effects. To avoid this simplification, Bode and Schmitz (2018) have developed similar models in MATLAB® and Modelica®. The MATLAB models are used for the simplified simulation of the system consisting of the power, heat and gas sectors. Those results are then validated and modified using dynamic models from the TransiEnt Library (Hamburg University of Technology, 2018) written in Modelica including the dynamic effects. That way it is ensured that the system is within the physical boundaries which might be violated by quasi-stationary models.

The system consists of renewable power generation, biogas production, electric energy storage technologies, Power-to-Gas units, gas storage volumes, Gas-to-Power units, heat producers and hot water storage units. Different configurations, i.e. combinations of storage technologies and heat producers, can be compared by cost.

Method

In this work, the existing models are extended, adding curtailment of renewables to reduce the size of the Power-to-Gas plants in particular because they are not sized according to the maximal load anymore which can reduce the system cost. The former models are also improved by adding more detail especially in the heating system while also simplifying some models and the control structure for a faster and more robust simulation.

The system costs are optimized using the quasi-stationary models in MATLAB employing the algorithm `patternsearch` leading to the reference case System 1 (S1). It is then designed in detail including the dynamic effects in Modelica.

In the next step, the effect of excess power utilization in the heating system compared to curtailment is investigated. In S2, the electric heat pumps use excess power and in S3, additionally the electric heating rods in the hot water storage tanks consume electricity. This way, the heat generation is shifted to times with high renewable electricity generation. These effects are highly dynamic and are easily captured by using Modelica.

Results

The combination of both MATLAB and Modelica in this context shows the advantages and disadvantages of each language. The quasi-stationary models in MATLAB are fast but not as versatile as the Modelica models which ensure good reusability and capture dynamic effects. Also, the models are easily understood and adapted.

The results show that a combination of lithium-ion batteries, Power-to-Gas plants, combined cycle gas turbines and electric heat pumps is the most cost efficient under the given assumptions. If you compare S1 to S2 and S3, cost reductions of 0.36 % (S2) or 0.64 % (S3) can be realized. The shift of the heat generation leads to less curtailed electricity and thus to an increase of the overall system efficiency. This means that most of the components are required in smaller sizes, which lowers the overall system cost, and only control has to be added to the system.

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Keywords: Integrated Energy System, 100% Renewables, Power-to-Heat, Energy System Analysis

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