Autonomous Liquid Hydrogen Production Plant Model

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Overview

The Northeast Asian region is a home for four out of the ten largest energy importers in the world: China, Japan, Republic of Korea and Taiwan. All of them declare the commitment to renewable energy and hydrogen technologies as a long-term energy development strategy. This region can become the World's largest green energy import hub receiving wind, solar and ocean energy from Latin America, solar and ocean energy from Australia and the Pacific, solar from the Persian Gulf, wind, tidal and hydropower energy from Russia's Arctic coast and north-west coast of the American continent. Often renewable energy projects in these regions assume no access to power grids, and new transport infrastructure is to be built to bring green energy to the international market [1]. A flexible and powerful research tool is needed for pre-feasibility studies of such projects.

Many studies (for example, [2-4]) dedicated to the combination of intermittent renewable electricity generation and water electrolysis technique for hydrogen production, compression, liquefaction, and transportation have been conducted. Transportation of renewable energy by sea includes implementation liquid organic hydrogen carrier (LOHC) technologies, using ammonia as a fuel, or employing other e-fuels shipping options. A range of sophisticated technical-economic models is developed to assess opportunities and economic patterns for [green] electro-hydrogen infrastructure establishment. This study expands the methodological tools by proposing a new model of green hydrogen production. A specific characteristic of this model is that it considers hydrogen both as a storage option to tackle the problem of renewable energy intermittence and as a final product when optimizing hydrogen production.

Methods

The core of the proposed research tool is an optimisation model of the autonomous green hydrogen production complex (AGP) [5]. The model minimizes the levelized cost of hydrogen production, choosing optimal time for compressed or liquid hydrogen (LH_2) injection to or withdrawal from storages taking into account local climate conditions and hydrogen shipment schedule. The outputs provide estimations for the cost level and cost structure of the liquefied hydrogen production.

The boundary of the mathematic system presenting AGP complex includes: 1) solar and wind power generators, connected directly to the AGP's power supply system, 2) combined water treatment and water electrolysis subsystems, which produce uncompressed hydrogen, 3) fuel cells as an auxiliary subsystem to produce electricity from stored compressed and/or liquid hydrogen, 4) compressed and liquid hydrogen storage facilities, enhanced with pipeline, regasification, and decompression subsystems to feed fuel cell, 5) liquefaction installation, fed by non-compressed hydrogen after electrolyser, or compressed hydrogen from the compressed hydrogen storage, 6) shipment terminal for liquid hydrogen (truck/tanker loading).

An important assumption is that the operation of the system under consideration characterised by linear functions, and all subsystem capacities are harmonised. In the model, it is possible to ship liquefied hydrogen produced by water electrolysis using electricity generated by solar and wind farms, within a single time slice. The driver for the AGP complex operation is an LH_2 shipping schedule.

In order to develop the research tool described, the front end and back end auxiliary tools were developed. The front end tool includes a database, and a set of models to calculate coefficients for the main optimisation model. One of the most important models is a web-related programme to assess PV and wind generation profile. The scope of capability to provide input data for solar and wind generation is limited only by web analytical climate databases, like ERA5 and CERES-SYN1deg. The back end tool comprise spreadsheets with charts to help analyse the model solution.

Results

In order to test the model, the cost of liquefied hydrogen produced by water electrolysis using wind and solar energy in Mongolia (east coast of Lake Khubsugul) and Japan (coastal areas of Yamagata Prefecture) was estimated. The estimations refer to the AGP complex with a capacity of 10 thousand tonnes of liquid hydrogen per annum. The model was applied to weather conditions at the each site for a series of years from 2015 to 2020. The analysis of the results obtained demonstrates model's relevance to the actual weather conditions, and the importance of technical and economic parameters of the AGP's equipment under assessment. Considering current costs of PV and wind farms, PEM electrolysers and fuel cells, other hydrogen technologies, discount rates etc., the average ex-works cost for weather conditions during 2015-2020 is 10.8 and 13.4 int. dollars 2020 per LH_2 kg for Mongolia and Japan, respectively.

The model can be used not only for cost estimation purposes but also for optimising hydrogen storage. Weather conditions in 2020 at the Japan's site – weak offshore winds in early May, late June and July, combined with a tight shipping schedule, force filling liquid hydrogen tanks (more effective for monthly and seasonal storage from the cost perspective) and then – a compressed hydrogen storage.

Further, employing the model, a case of power supply by a high-voltage direct current transmission line from Mongolia to Japan was investigated to assess the viability of green electricity import for domestic green LH_2 production in Japan. The results demonstrate that power supply from Mongolia for the purpose of green LH_2 production in Japan is competitive with green LH_2 imported from Mongolia only if the power transmission line's capacity factor is considerably higher than that of solar and wind farms in the described location in Mongolia, and there are no restrictions for green power transmission.

Conclusions

The research tool destined for pre-feasibility autonomous liquefied hydrogen production studies was developed. The tool estimates levelized cost of green hydrogen under local climate conditions. The main characteristics of the hydrogen production plant modelled are as follows: 1) Only renewable energy is used to produce hydrogen; 2) Electrolysers are used to transform electricity into hydrogen. Fuel cells or batteries are used to power the plant when a lack of renewable energy generation occurs; 3) The plant is equipped with compressed and liquefied hydrogen storages to ensure daily and seasonal energy supply and production shipment; 4) An hourly shipment plan specifies the demand for the plant output.

To test the developed tools, the cases of an AGP complex for locations in Mongolia and Japan were analysed. The results shown that the model is sensitive to weather, economic and technical parameters. The model is proposed as a basis for solving a wide range of issues related to combination of renewable energy and hydrogen technologies development, including power-hydrogen infrastructure projects in Northeast Asia.

References

1. Otsuki T., Komiyama R., Fuji Y. Techno-economic Assessment of Hydrogen Energy in the Electricity and Transport Sectors Using a Spatially-disaggregated Global Energy System Model, Journal of the Japan Institute of Energy, 98, 62-72（2019), pp.62-72

2. Samsatli S., Staffell I., Samsatli N.J. Optimal design and operation of integrated wind-hydrogen-electricity networks for decarbonising the domestic transport sector in Great Britain // Int J Hydrogen Energy. 2016. V. 41. P. 447–475. DOI 10.1016/j.ijhydene.2015.10.032

3. Samsatli S., Samsatli N.J. A multi-objective MILP model for the design and operation of future integrated multi-vector energy networks capturing detailed spatio-temporal dependencies // Appl Energy. 2018. V. 220. P. 893–920. https://doi.org/https://doi.org/10.1016/j.apenergy.2017.09.055.

4. Otsuki T., Shibata Y. Feasibility Study on Synthetic Methane Using an Electricity and City Gas Supply Model. Written by the authors for the 36th Energy Systems, Economy and Environment Conference, reproduced and uploaded on IEEJ website with the permission of Japan Society of Energy and Resources. http://eneken.ieej.or.jp/data/8954.pdf

5. Sergei P. Popov, Methodological approach to the study of the electro-hydrogen system in Northeast Asia, International Journal of Hydrogen Energy, DOI 10.1016/j.ijhydene.2022.02.191