Storage of Renewable Energy in Hydrogen Using Power-to-Gas Technology

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ABSTRACT

In Kamchatka region up to 30% of electricity is produced from renewables, to avoid curtailment by the grid operator the excess power should be used for hydrogen production by water electrolysis. For each 1% of saved geothermal steam 92 t of H₂ can be annually produced. Blending the produced hydrogen with natural gas is a promising option due to the availability of existing infrastructure. The H₂/CH₄ mixture suits for commercial and domestic use, hydrogen as well can be separated from the mixture and used in fuel cells.

INTRODUCTION

The share of renewable energy sources (RES) in electricity generation increases rapidly. Variable nature of RES is one of their major drawbacks, capacity factors are quite low: 0.13-0.54 for wind and 0.10-0.35 for solar PV [1]. Integration of the renewables into grid raises several problems [2]:

- Matching supply and demand (market level—hourly perspective). In periods with high RES generation, supply may exceed demand, creating negative electricity prices in the spot market. On the other hand, for periods with low RES generation costly back-up capacity has to be available.
- Safe network operation (balance of supply and demand on a second to minute basis). To accommodate unpredicted fluctuations, grid operators need to provide increased reserve power on the balancing market, and energy production may need to be curtailed.

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Current power storage capacity is just under 3% of global electricity generation capacity (or 150 GW) and is dominated by a single technology, pumped storage hydropower (PSH) [3]. Hydrogen for energy storage fits into a global sustainable energy strategy for the 21st century that confronts the three-pronged challenge of irreversible climate change, uncertain oil supply, and rising pollution. The role of hydrogen at national and international strategic levels relies entirely on renewable energy and energy efficiency. Hydrogen would play a crucial role in medium and long distance road and rail vehicles; in coastal and international shipping; in air transport; and for longer-term seasonal storage on electricity grids relying mainly on local renewable energy sources and feedstocks [4].

Hydrogen produced from renewable electricity by water electrolysis could facilitate the integration of high levels of variable renewable energy into the energy system [5]. Power-to-Gas is defined as the production of a high-energy density gas via electrolysis of water. Blending hydrogen with natural gas is a promising option due to the availability of existing infrastructure. The key challenge today is to identify concrete short-term investment opportunities, based on sound economics and robust business cases, initial business cases will likely be based on producing green hydrogen and supplying it to industry and mobility ("Power-to-Hydrogen" and "Hydrogen-to-X") [6].

RENEWABLE POWER GENERATION IN RUSSIA

RES share in Russia is very low due to cheap and abundant fossil fuels, data on wholesale electricity market show that renewables generated only 0.01% of the total electricity in 2016 and about 0.04% in 2017. On the other hand, about 2/3 of Russia's territory with the population about 20 million is not covered by unified grid system and these regions supplied by isolated grids, where renewables can play a greater role [7]. There are ca. 900 diesel power stations generating 2.54 billion kWh/year (2% of total generation in Russia) with generation cost in the range 0.25-2 Euro/kWh [8]. The power supply of isolated regions is heavily subsidized from the federal and regional budgets and causes significant environmental damage.

The only region in Russia with a high share of RES is isolated energy system of Kamchatka, where operate geothermal power plants including Mutnovsky GeoPP-1 (50MW), Verkhne-Mutnovsky GeoPP (12 MW), and Pauzhetsky GeoPP (11.0 MW) [9]. Today the Mutnovsky power plants produce 27-30% of electricity generation in the Central power district of Kamchatka, which covers 65% of the region and supplies power to 360,000 people (95% of the population). In 2016 the geothermal power was sold to the grid for 2.69 RUB/kWh (ca. 0.045 $/kWh), while generation from fossil fuels cost 5.01 RUB/kWh (ca. 0.08 $/kWh), thus further development of geothermal power stations in Kamchatka can be feasible. The most promising projects are expansion of the Mutnovsky and Verkhne-Mutnovsky GeoPPs, a use of waste brine in a combined power unit can give additional 8 MW

Although geothermal power production has a very high capacity factor, it has problems with integration to the grid. Annually 12.3% of geothermal steam is lost [11], and a significant part of the losses arises from a curtailment by the grid operator. At night, the load can be dropped by 60% in favor of combined production of electricity and heat from fossil fuels at thermal power plants.

POSSIBLE HYDROGEN PRODUCTION FROM GEOTHERMAL POWER

Various hybrid schemes have been proposed for the geothermal cycle improvement, including combination with another source of energy [12], co- or multi-generation including hydrogen production greatly increases the efficiency of geothermal systems [13, 14]. Electrolyzers of MW-class are available on the market, at 10 bar output pressure their efficiency is between 52 and 62% (LHV) for alkaline and 57–64% for PEM models [15].

Calculations by thermodynamic model, described in [11], show that there is a potential to increase power production on the Mutnovsky GeoPP-1 by the use of energy of separated liquid and by decreasing steam losses (see Figure 1).

![Figure 1. Enthalpy and exergy balances for the Mutnovsky GeoPP-1.](image)

Both thermal and exergy efficiencies of the plant are linear functions of technological steam losses. The steam losses at Mutnovsky GeoPP-1 are in the range
from 3.1% - 18.8% (see Figure 2). Since a significant part of losses arises from curtailment to demand side management, there is a possibility to increase generation and use additional energy, e.g. for hydrogen production. If a full load of turbines is maintained, there will be excess energy for water electrolysis. It appears that for each 1% of saved steam 92 t of H$_2$ can be annually produced.

Standards permit to add around 10% of hydrogen into natural gas. According to the Russian standard, GOST 5542-2014 components of natural fuel gases are not normalized, and possible hydrogen content is only restricted by requirements for Wobbe index and low heating value.

CONCLUSIONS

In Kamchatka region up to 30% of electricity is produced from renewables, to avoid curtailment by the grid operator the excess power should be used for hydrogen production by water electrolysis. Blending the produced hydrogen with natural gas is a promising option due to the availability of existing infrastructure. The H$_2$/CH$_4$
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