RENWABLE ELECTRICITY STORAGE WITH AMMONIA FUEL : A CASE STUDY IN JAPAN WITH OPTIMAL POWER GENERATION MIX MODEL

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Overview

Renewable energy, such as photovoltaic (PV) and wind, is being rapidly installed and prioritized for resolving climate change and energy security issues in Japan. Integration of renewable energy into power gird, however, requires technical measures such as rechargeable battery, flexible power generation, renewable power output curtailment and demand response. As one of those measures, this paper highlights renewable electricity storage with ammonia fuel, which is also one of technical options for building hydrogen energy system. Ammonia fuel is regarded as promising hydrogen carrier with relatively higher energy density to satisfy energy requirements for stationary solid oxide fuel cell, and carbon-free renewable-based ammonia, which potentially contributes for low-carbon chemical industry as well, will decarbonize energy system at less invensment cost for infrastructures because well-established ammonia transport and storage infrastructures are already in place. The availability of ammonia is similar to propane (LPG) which is easily transportable at low pressures, and a lot of R&D effort has been dedicated for ammonia to be employed in direct combustion technology and transport fuel. This presentation attempts to investigates installable potential of renewable-ammonia storage system in power gird of Japan under extensive penetration of renewable by employing an optimal power generation mix model. The model is upgraded from the authors' previously developed model [1][2] formulated as a large-scale linear programming model.

Methods

The authors try to develop an optimal power generation mix model considering renewable-based ammonia storage system under various technical constraints employing linear programming technique based on the authors' previous work [1][2]. The highlight of the model consists in detailed geographical resolution derived from 135 nodes and 166 high-voltage power transmission lines (Fig.1) and in detailed temporal resolution derived from 10 minutes in a whole year. The minimization of the objective function, comprised of facility and fuel cost, enables us to identify the best mix for power generation and capacity of the country's power plants. Regional wind and PV output are estimated at 10-min resolution using a detailed meteorological database called AMeDAS [3] in Japan. Concerning renewable-based ammonia storage system (Fig.2), electrolyzer converts electricity from wind and PV into hydrogen, and the hydrogen is used to produce ammonia, through Haber-Bosch process, which is liquefied and stored in ammonia tank for later combustion in stationary solid oxide fuel cell (SOFC).

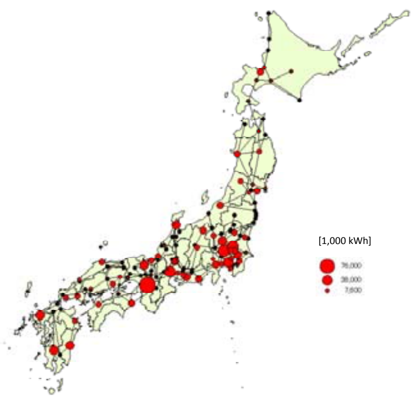

Fig.1 Power grid and demand in optimal power generation mix (OPGM) model

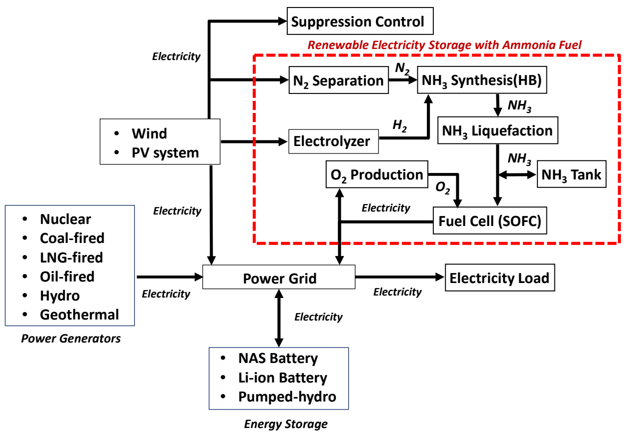

Fig.2 OPGM model combined with renewable-based ammonia storage system

Results

Computational simulation is conducted under CO_2 regulation scenario which assumes 50 percent, 60 percent, 70 percent and 80 percent reduction from the level of no regulation scenario. In addition, cost of ammonia technology (electrolyzer, ammonia production and storage, SOFC) is assumed as 80% reduction from the reference values, because annonia production is marginal in the reference cost values. As a preliminary analysis, it turns out that strict carbon regulation policy accelerates the installations of PV, wind and energy storage system, such as NAS battery and ammonia storage, which replace carbon-intensive thermal power plants (Fig.3). In CO_2 80% reduction scenario, 10% of wind output is utilized for ammonia production, and wind-based ammonia is observed in Tohoku, Kyushu and Hokkaido area, while ammonia is not so much produced nation-wide from PV output and, however, 30% of PV output is utilized for ammonia production in Kyushu area. On the whole, as shown in Fig.4, renewable-ammonia production is introduced in the northern area (Hokkaido (Fig.5) and Tohoku) and southern area (Kyushu) under strict carbon regulation.

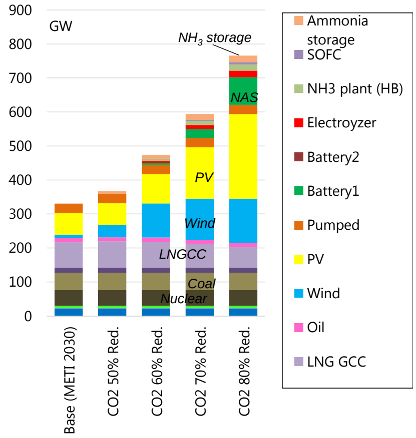

Fig.3 Power generation capacity in CO_2 regulation scenario

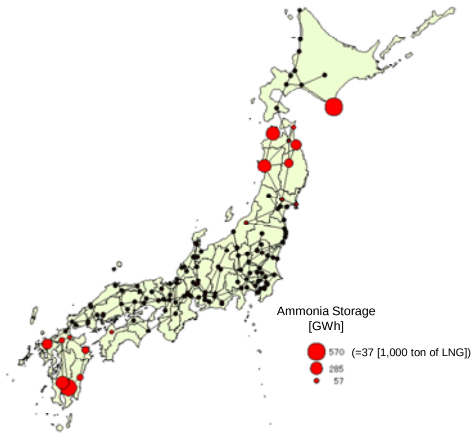

Fig.4 Ammonia storage capacity in CO_2 80% reduction scenario

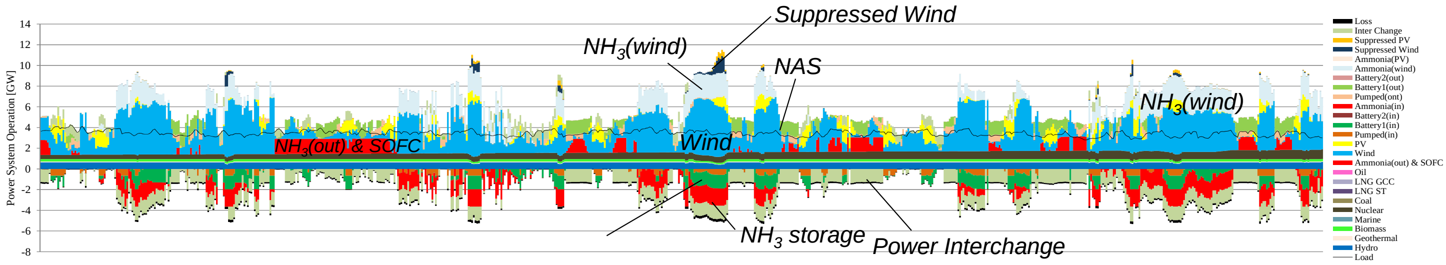

Fig.5 Optimal power dispatch in May at Hokkaido (northern region) under CO_2 80% reduction scenario

Conclusions

Massive integration of renewable energy is a great technical challenge due to its uncertain variable output. This paper develops an optimal power generation mix model considering renewable-ammonia storage system. The results reveal that cost reduction of ammonia technology and carbon regulation are prerequisite for promoting ammonia produced from renewable energy. Future agenda consists in considering ammonia supply for transport and industrial usage and hydrogen technology such as compressed storage, liquid hydrogen and organic hydride technology.

Acknowledgment

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References

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