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Contribution of hydrogen-related technologies for realizing decarbonized power systems

Matsuhashi R.*

1. Introduction

Due to the serious concern on the global warming, decarbonization of energy systems are becoming the most significant requirement all over the world. While many countries focus on the decarbonization in 2050, Japanese government also submitted a target to United Nations, in which our country attempts to realize the decarbonized society in the latter half of this century.

In this document, feasibility of the decarbonized power systems is explored. In particular, contribution of hydrogen-related technologies is discussed in order to realize the systems.

2. Aspects to implement hydrogen-related technologies for a decarbonized society

In a decarbonized society, hydrogen is expected to play a significant role.[1] However, we must take various aspects into consideration to implement hydrogen-related technologies.

One of the important aspects is a large scale integration of variable renewable power sources. In Japan, solar power generation has shown explosive growth mainly because of the feed-in-tariff institution. Although this contributes to decarbonize power systems, operators of power systems have to prepare large quantity of reserve capability, due to forecast errors in solar power generation. They are forced to operate many partial load fossil-fired power stations, so that the efficiency and the cost of power systems become worse. Thus the management of forecast errors in renewable power sources is significant to avoid the inefficient power system operations. In this respect, hydrogen production managing the forecast error deserves attention[2].

Furthermore, increase of solar power generations influences a transient stability of power systems, since they do not have inertia, which synchronous generators have. Due to a page limitation, the author would appreciate that readers could refer to the details of the transient stability.[3] In short, it is necessary to maintain a certain share of synchronous generators. In this context, hydrogen produced from renewable power sources through electrolysis could be used for power generation by synchronous generators, which contributes to maintain the transient stability. As such, we could realize decarbonized power systems even from variable renewable power sources[3]. This system is described more in details in section 3.

On the other hand, co-benefits of hydrogen production should also be taken into consideration to improve acceptability of the system. For instance, a co-benefit could be realized in the energy consumption for aquaculture as follows.

Most of energy demand for aquaculture such as shrimp farms is consumed by aeration system which uses electric motors to drive aerators for improving dissolved oxygen in ponds.[4] Therefore, we proposed an optimal design for advanced aeration system in which electricity by renewable power sources produce onsite pure oxygen through electrolysis to control dissolved oxygen level in shrimp ponds.[4] The optimal results showed that life cycle cost and CO_2 emission of the proposed system were lower than the conventional mechanical aeration system.[4]

3. A case study to implement hydrogen-related technologies for a decarbonized society

In this section, the author explains results of a case study to implement hydrogen-related technologies in the power system of Kyushu region. For detailed information on developing the mathematical model, the readers are appreciated to refer to the article.[3]

Evaluation results are shown in Figures 1, 2, 3, 4, 5 and 6. Figure 1 shows the relationship between constraints on CO_2 emissions rate and variable costs of power generation. The CO_2 emission rate at 0% means that decarbonized power system is realized.

The variable costs change gradually when the constraints are higher than 10%. When the constraints are lower than 10%, the costs change steeply.

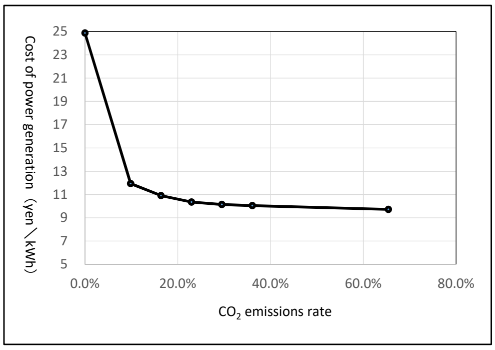

Figure 1. Relationships between CO_2 emissions rate and costs of power generation

Optimal capacities of hydrogen storage also change steeply, when the constraints are higher than 10% as shown in figures 2 and 3. In particular, the optimal capacity becomes a huge value of 1.8 billion Nm^3 in the case of the decarbonized power system.

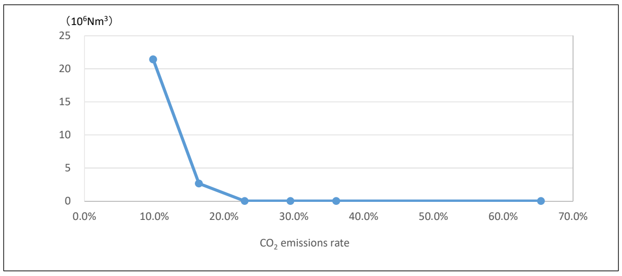

Figure 2. Relationship between CO_2 emissions rate and capacities of hydrogen storage in the case that CO_2 emission rate is higher than 10%.

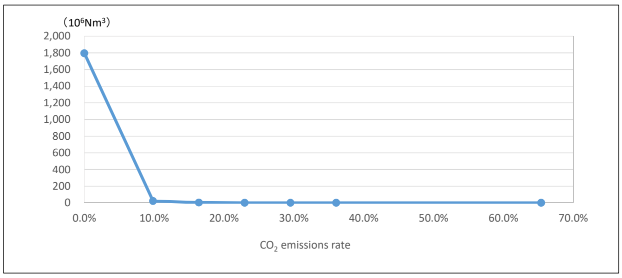

Figure 3. Relationship between CO_2 emissions rates and capacities of hydrogen storage.

Figures 4 and 5 show annual changes in hydrogen storage on the CO_2 emissions rates at 10% and at 0%, respectively. The figure 4 shows weekly changes of stored hydrogen, whereas the figure 5 shows seasonal changes of stored hydrogen. Namely, operation modes shift from weekly to seasonal changes to realize the decarbonized power system.

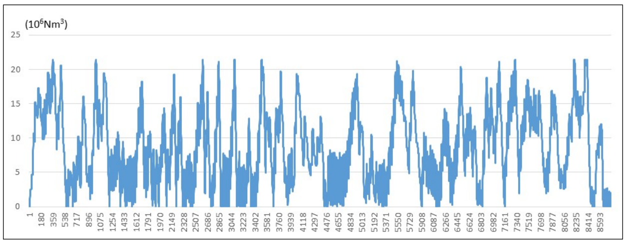

Figure 4. Annual change in storage of hydrogen in the case that CO_2 emission rate is 10%.

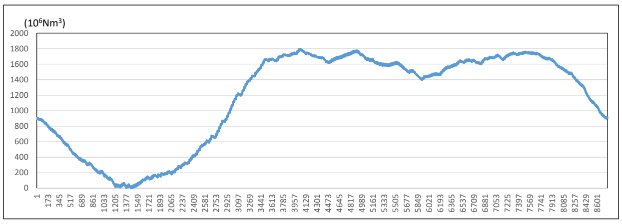

Figure 5. Annual change in storage of hydrogen in the case that CO_2 emission rate is 0%.

There is an argument that the capital investment of hydrogen storage is prohibitively high in the decarbonized system. This is because hydrogen storage must absorb seasonal change in solar radiation, so that we could use hydrogen for the entire capacity only once in a year. However, this argument is missing the significant aspect as follows. The change in stored hydrogen in a week shows ripples as shown in figure 6, meaning that the storage quantity increase and decrease even in short periods. The sum of the change in absolute values amounts to 8.2 times of the storage capacity. Therefore the burden of the capital investment of hydrogen storage could be decreased by 4.1 times even in the decarbonized system.

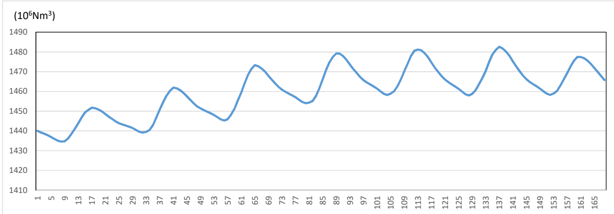

Figure 6. Change in storage of hydrogen in a week in September in the case that CO_2 emission rate is 0%.

Nevertheless, the cost of power generation becomes high according to Figure 2. Thus we need further breakthroughs on storage technologies of hydrogen to realize economically acceptable decarbonized systems.

4. Conclusions

In this document, the author first explains the relationships between the trends toward decarbonized societies and necessity of hydrogen-related technologies. Then the case study was described to introduce hydrogen in a decarbonized power system. Although hydrogen is expected to play a significant role in the decarbonized systems, it is difficult to project when and how to introduce hydrogen-related technologies. It is influenced by the speed to transition into decarbonized systems, techno-economic progresses of hydrogen-related technologies, and institutions on power and energy systems. Therefore we must promote developments of the technologies and the systems taking all the above factors into consideration.

References

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*matu@enesys.t.u-tokyo.ac.jp