Examination of Hydrogen Production Efficiency Using Surplus Energy from the Renewable Energy 3020 Implementation Plan in South Korea

Philseo Kim [a], So-Bin Cho [a], Man-Sung Yim [a*]
[a]*Nuclear and Quantum Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of KOREA*
[*]*Corresponding author: msyim@kaist.ac.kr*

1. Introduction

Following the government's 'Renewable Energy 3020 Implementation Plan' announced in 2017, Korea is planning to increase the share of renewable energy generation to 20% of the total electric production by 2030 [1]. In addition, according to the current government's 'Korea Hydrogen Economy Roadmap 2040,' Korea must meet the target hydrogen production cost of 4,000 won/kg in 2030 and the supply of 1.94 million tons/year to accomplish the hydrogen economy through activation of hydrogen use [2].

Therefore, in this study, we tried to find a way to contribute to hydrogen production according to the implementation plan of the renewable energy 3020 plan. We analyzed how to apply the excess energy of the national power system due to the expansion of renewable energy to hydrogen production using an electrical connection method.

2. Methods and Results

2.1 Systemic Modeling Assumptions

- Electricity demand: Electricity demand data was selected based on the electricity demand forecast according to the '8th Basic Plan for Long-term Electricity Supply and Demand.' According to this plan, it is predicted to increase by about 1.3 times compared to 2017. Therefore, the hourly electricity demand data profile was scaled up by 1.3 times of the hourly electricity demand profile at 2017/04/27.
- Nuclear energy: The generation capacity of nuclear energy is set as 20.4GW with 20 nuclear power plants according to the 'Renewable Energy 3020 Implementation Plan.'
- PV: According to the '8th Basic Plan for Long-term Electricity Supply and Demand,' the generation capacity of photovoltaic energy is 33.5GW, and the wind power is about 17.7GW. However, instead of using wind power data for this study, the capacity of photovoltaic energy was increased to 43.59 GW (about 30% increase over 33.5 GW). The PV hourly generation profile in this study scaled up its generation profile data of Handong 3.5MW PV station located in Korea into 43.59 GW.
- Coal: According to the '8th Basic Plan for Long-term Electricity Supply and Demand,' the generation capacity is 39.9 GW. We set the number of coal power plants as 70 in this study.
- LNG: According to the '8th Basic Plan for Long-term Electricity Supply and Demand,' the generation capacity is 44.3 GW. We set the number of LNG power plants as 200 in this study.
- Hydrogen electricity incentive: In this study, it was assumed that 50 won/kWh was incentivized to use the surplus electricity into hydrogen generation. Hydrogen generation plants get incentives while using the surplus energy into hydrogen generation in our assumptions. We set 20MW regulation for each of the 600 electrolyzer plants. Therefore, the maximum possible power consumption could be 12 GW(=20MW*600).
- Power grid: The power grid in this study assumes complete transmission availability in South Korea, which means that electricity can flow anywhere in Korea. The hydrogen generation was analyzed by using a centralized dispatch approach without considering transmission and distribution losses. In addition, the loosely coupled Nuclear-Renewable Hybrid Energy System (NRHES) was assumed in this study.

The systemic modeling assumptions were based on the paper from Cho and Yim [3]. Still, the underlying assumptions of the previous paper were modified in this paper as an approach to using the surplus energy into hydrogen production. The capacity values of each energy source are from the '8th Basic Plan for Long-term Electricity Supply and Demand' [4].

2.2 Optimization using MILP method

To assess the day-ahead optimization, the MILP (Mixed-Integer Linear Programming) method was employed in this study. This method was also used to optimize the demand response in Nuclear Hybrid Energy System.

The optimization in this study aims to produce electricity at the lowest cost while satisfying the set operating constraints on the one-day power supply. In this optimization process, it analyzes how nuclear power, LNG, and coal distribute power supply by subtracting PV hourly generation output profile from electricity demand to perform dispatch scheduling. It is because there is an underlying assumption that all of the renewable energy generated by PV is used. Besides, surplus power energy is assumed to be used for hydrogen production. Constraints include capacity limitations for base loads such as coal, nuclear power, LNG, minimum power generation, start time, ramp rate, the power balance between supply and demand.

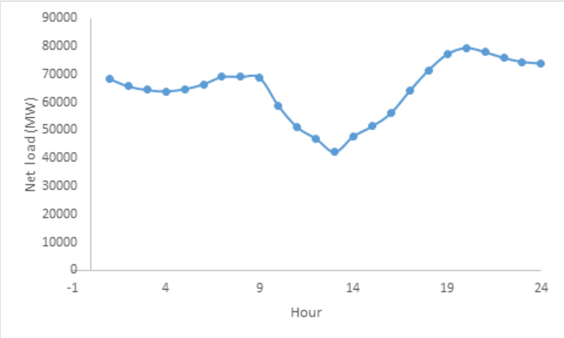

Fig. 1. Net electricity load demand

2.3 Cases

For this study, four cases were selected to compare the surplus power for hydrogen generation and the generation cost of each case. The specification of each case is described below the table.

Table I: Specification of analysis cases

	Case 1	Case 2	Case 3	Case 4
Capacity factor of nuclear energy (%)	80	85	90	100
Nuclear power generation output (GW)	16.32	17.34	18.36	20.4
Ramp rate of nuclear power plants (MW/min)	0	0	0	0
Capacity factor of coal energy (%)	85	85	85	100
Coal power generation output (GW)	33.915	33.915	33.915	39.9
Ramp rate of coal power plants (MW/min)	0	0	0	10
LNG power generation output (GW)	44.3	44.3	44.3	44.3
Ramp rate of LNG power plants (MW/min)	20	20	20	20

The nuclear power generation output of Case 1 is 16.32GW, which is an 80% capacity factor of 20.4GW. Case 2 is an 85.% capacity factor, which is 17.34GW. Case 3 is a 90% capacity factor, which is 18.36GW.

The ramp rate of nuclear and coal power plants was set as 0MW/min in Case 1,2, and 3. It is because we would like to see the amount of surplus energy into hydrogen production when nuclear and coal power is stable baseload energy sources.

Case 4 is to see when there is no surplus energy used for hydrogen generation. In this case, it is assumed that the capacity factor of nuclear power and coal power is 100%. Besides, we set that the ramp rate of coal power plants as 10MW/min in Case 4.

2.4 Results

Table II: Optimization Results

	Case1	Case 2	Case 3	Case 4
Surplus Energy (GWh)	13.16	16.24	21.08	0
Generation Cost (KRW/kWh)	80.563	80.557	80.703	76.378
The amount of hydrogen that can be produced per year (ton)	80056	98793	128236	0
The proportion of production compared to the government's hydrogen supply target in 2030 (%)	4.13	5.09	6.61	0
Nuclear power generation ratio (%)	21.96	23.33	24.70	27.4
Coal power generation ratio (%)	45.63	45.63	45.63	50.0
LNG power generation ratio (%)	20.08	18.89	17.79	9.5

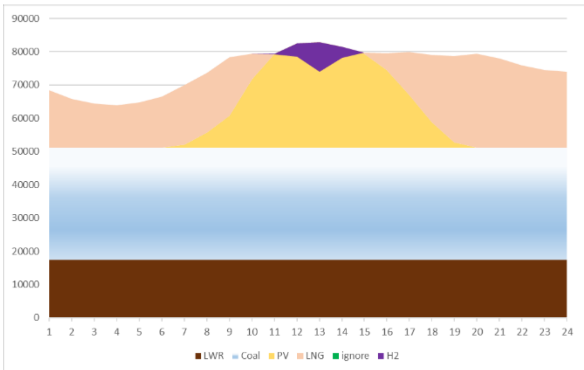

Fig. 2. Case 2 Results

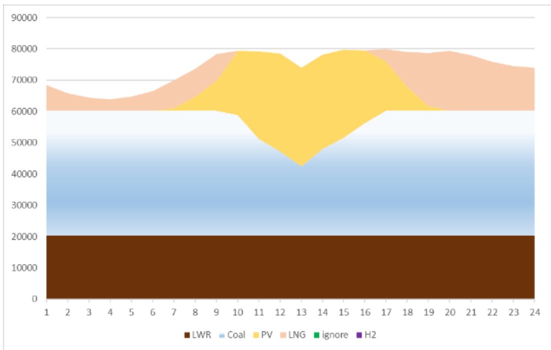

Fig. 3 Case 4 Results

As a result of the optimization, it can be seen that when the nuclear power capacity factor is 80%, 13GWh of surplus power is generated for one day. In addition, it can be seen that as the capacity factor of nuclear power plants increases, the amount of surplus power used for hydrogen production increases. According to the optimization result of Case 3, it can be confirmed that the surplus power of about 21 GWh is generated when the capacity factor of nuclear power plants is 90%. That is, if nuclear power does not operate in load-following mode, the higher the capacity factor of nuclear power, the higher the surplus power production for hydrogen production.

However, it is not enough to use this surplus power to produce 1.94 million tons of hydrogen, which is the government's annual supply target according to the "The roadmap for ramping up the hydrogen economy." Conservatively, about 60 kWh/kg of electricity is required to produce hydrogen through electrolysis. As a result of calculating the predicted annual amount of hydrogen produced using this optimized surplus power for each case, it was found that in all cases, it could be produced only within 10% of the government's hydrogen supply target.

The daily electricity power demand is constant from Case 1 to 4. However, the higher the capacity factor of nuclear energy, the more excess power is generated. Therefore, an additional incentive fee should be paid so that it can be used to produce hydrogen as much as the surplus power remaining to satisfy the electricity demand. Therefore, the cost of generating electricity per day is 80.563 won/kWh in Case 1, but it is about 80.703 won/kWh in Case 3. This is only 1.055 and 1.057 times higher than the generation cost in Case 4.

3. Conclusions

Several conclusions were drawn from the analysis of the surplus energy to be used for hydrogen production through the NRHES system in South Korea. First, if nuclear power plants do not operate in load-following mode, the amount of surplus energy is increased when the capacity factor of nuclear power plant increases. Secondly, to meet the demand and supply of electricity, it is necessary to operate the LNG in load-following mode. It is plausible because LNG has the highest generation cost among the three primary energy sources (nuclear, coal, LNG). Finally, if the surplus power derived from the 'Renewable Energy 3020 Implementation Plan' is used for hydrogen production, the hydrogen amount is only within 10% of the government's annaul hydrogen supply target in 2030. Therefore, to increase the supply of hydrogen to meet the hydrogen supply target, it is necessary to use an additional capacity of nuclear power as much as possible.

REFERENCES

[1] "Renewable Energy 3020 Implementation Plan," *Ministry of Trade, Industry, and Energy*, 2017.

[2] "The roadmap for ramping up the hydrogen economy," *Ministry of Trade, Industry, and Energy*.

[3] S. Cho and M. Yim, "Examining the feasibility of nuclear-renewable hybrid energy system in Korea: A case-based analysis of high penetrations of solar energy," *Int. J. Energy Res.*, no. May 2019, pp. 1–11, 2020.

[4] "The 8th Basic Plan for Long-Term Electricity Supply and Demand," *Ministry of Trade, Industry, and Energy*, vol. 2017–611, 2017.