# Design and Optimization of Intelligent Power System Integrated Floating PV/Hydrogen Energy

Chankyo Kim, Sangwook Park*

*Department of Mechanical Engineering, Seoul National Univeristy, Republic of Korea*

**Abstract**

The recent study dealt with potential solutions for the replacement of fossil fuel based energy resources with a sustainable green energy resource. To overcome the existing barriers of each renewable energy resource, the integrated floating PV (FPV)/hydrogen fuel cell was proposed in this study. HOMER Software was used for optimization of the integrated system and MATLAB for data analysis. PV system over the lake provides the majority of load, produces hydrogen as backup resource, and stores excess electricity in batteries to prevent instant energy dissipation. The results of the study were: saving massive lands and cost by implementing FPV systems, maximizing power generation by applying phosphoric acid fuel cell (PAFC), compensating the intermittent drawback of solar energy using novel energy storage system. $11.3M (9% of net present cost) was saved by installing FPV compared to overland PV systems. Stored hydrogen was used to meet the electrical energy demand and generate additional thermal energy corresponding to 13.7% of total electricity generation. Vanadium redox flow batteries (VRBs) combined energy storage enables to expand system feasibility in city size power generation and prevent energy dissipation with 5% of loss of power supply probability (LPSP). FPV with hydrogen systems and batteries provides entire electricity demand without any grid connection or fossil fuel usage, where 26.6GWh/year electricity is consumed at $0.300/kWh levelized cost of electricity (LCOE). From the above results, it was judged that integrated FPV/hydrogen fuel cell system can be a sustainable and profitable alternative for large scale energy demand.

*Keywords:* Optimization, Fuel cell, Energy storage, Floating Photovoltaic, Solar hydrogen

## 1. Introduction

Historically, energy has been established as one of the indispensable resource for the survival of living organism; especially human beings have been developed the way of use of energy in various and creative approach. Naturally, energy consumption for industrial or residential applications has given rise to steady increase followed by world's population growth. According to the annual flagship publication World Energy Outlook (WEO) released by the International Energy Agency(IEA)(Cozzi (2020)), although the temporary reduction in global electricity demand arised from COVID-19 occurred in 2020, it is expected to recover to pre-crisis levels by 2023 and then rises by 0.8% per year through to 2030, driven by the electrification of mobility and heat. Recently, over 80% of global energy is produced based on fossil fuels and their continued utilization generates greenhouse gases that have led to global warming or direct physical threat (Council (2017)). In order to manage the rise of electricity demand as well as to minimize these risks result from greenhouse gas (GHG) emissions, the concept of renewable energy system including photovoltaic, fuel cell, and wind generator have been proposed and widely implemented (Rad and Vaziri (2020)).

Solar power plants using photovoltaic (PV)

*Corresponding author.

cells are one of the renewable energy generating systems which are getting more competitive with traditional power plants. Fuel cell also show great possibility of performance as green power source because of many merits they have (such as high efficiency, flexible modular structure, small area occupancy and low-level emission of greenhouse gases). However, total photovoltaic systems occupy large site areas due to low efficiency of PV cells and they are not available to cater to dynamic electricity demand through a day because of nighttime periods or undesired weather conditions such as rainy season. The expensive capital cost of fuel cell power plants is a barrier to the popularization of the technique.

To improve this existing problem of renewable power system, development on new energy resource such as hydrogen and combined renewable power production system has been conducted. For example, hybrid renewable energy system (HRES) based on combined technologies of renewable energy has been proposed to foster energy reliability, stability, effectiveness and cost efficiency without GHG emissions (Park and Sangwook, 2019). Even so, components of the HRES have to be designed precisely to generate energy at an optimal point to demonstrate its full potential.

While batteries, compressed air, or supercapacitors function as energy storage system, they lack enough energy capacity and storage time span. To deal with large scale of dynamic energy demand and undesirable weather condition, hydrogen has been proposed to a carbon-free seasonal storage medium (Council (2017)). It is a novel resource to store energy with large scale and long-term duration. Hydrogen storage system even has additional value of generating thermal energy from waste heat using heat recovery of combined-heat-and-power systems (CHP systems), (Ma (2021)). In addition, vanadium redox flow batteries (VRBs) are integrated as an auxiliary energy storage method to redeem the shortcomings of hydrogen storage system (Li (2019)).

Recently, a number of researches of FPV (installation of PV above the water) have been conducted to solve the major drawback of conventional solar power system that the constructing the plants always account for intense land area which will always be a premium expenditure. So, the FPV systems can become proper logical alternatives by utilizing large land area above the reservoirs or lakes. Moreover, in virtue of lower module temperature in FPV (Choi (2014)), cooling effect improves its power efficiency by 11% compare to inland PV systems. It also reduces reservoir evaporation and algae growth by shading the water which can prevent quality degeneration of reservoirs that the FPV systems has been set to operate (Perez (2018)). According to a research performed in Yuvacik Dam, Turkey, the study concluded that the solar radiation is the most influential impact on water lost by presenting water evaporation data in the Dam area (Temiz and Javani (2020)). In this study, HOMER Software is used for the optimization purposes. Furthermore, analyses using MATLAB are conducted in order to assess the feasibility and effectiveness of HRES in providing the required energy demand. As a comprehensive approach, feasibility analysis of the entire system to supply predefined dynamic electricity load demand has been demonstrated in order to determine most effective composition of components of HRES. Our novelty in the article is presenting renewable energy power plant with zero GHG emissions supported by new strategy of energy storage system by using hydrogen as major energy storage and auxiliary storage medium of VRBs integrated with floating PV system that fully exploits the advantage of photovoltaic power plant system with compensating drawbacks of ground-mounted photovoltaic power plant system. In respect to novelty and benefit, the HRES proposed in the paper offers electrical power supply accord to the size of city coping with dynamic change of electricity through the year, 100% renewable energy power plants without GHG emissions, cost saving by conserving land areas by utilizing floating PV system, and additional thermal energy generation by selecting hydrogen fuel cell.

## 2. Hybrid renewable energy system description

The system is mainly aim to supply large scale of electricity generated by renewable energy resources, to proposed combined energy storage medium of hydrogen and battery, to improve financial feasibility by green energy. Fig. 1 shows the schematic of the overall system proposed in this study, consists of FPV, bidirectional converters, hydrogen fuel cell, electrolyzer, hydrogen tanks and batteries with electrical load and additional thermal load. Floating PV modules function as major renewable energy sources, hydrogen tank, fuel cell power system and batteries work as backup green energy sources. Fuel cell system and electrolyzer have high costs, but these components compensate dynamic power fluctuations and provide additional power at peak hours supporting floating PV system. Moreover, fuel cells are able to cover the deficiency in the required electricity in such case where solar energy generation is insufficient (e.g., monsoon season, during nighttime, etc.) While hydrogen tanks store major excess renewable energy, integration of VRBs enhance solar energy conversion efficiency that saves energy dissipation.

In this research, comparison of two separate scenarios of 100% renewable energy power plants were considered priorly. The first scenario was to store backup energy using hydrogen storage system only and the second scenario was to utilize combined energy storage system consisting of hydrogen storage system and vanadium redox flow batteries (VRBs). After analyzing the pros and cons of forementioned two scenarios, examination of the best case of the optimized HRES components was presented.

The energy dispatch algorithm used in the research is shown in Fig. 2. HOMER calculates power generation by FPV using given data of load demand and metrological data. If the electricity supplies sufficient electrical load demand first, surplus electric power is saved as hydrogen. Taking certain time during hydrogen conversion, the batteries store the electric power during the conversion stages. If the electricity generated from the floating PV does not match the electrical load demand, stored energy in the batteries and hydrogen tank supply the power. HOMER evaluates every possible scenario and finds optimal design of system with minimized Levelized Cost of Energy (LCOE) (Fig. 3). If the total electricity production by the FPV-FC-ESS hybrid system is insufficient to match the electricity load demand, proposed system would be reported as no optimal solution that the design should be modified.

### *2.1. HOMER PRO simulation model*

HOMER (Hybrid Optimization of Multiple Energy Resources) Pro is a power system optimization software developed by U.S National Renewable Energy Laboratory (NREL). It is employed in order to determine most feasible component configuration of the power system to supply specific energy demands. It finds the optimal design of proposed power plants, calculates further various evaluation indexes such as total net present cost (NPC) and greenhouse gas emissions affected by varying system components. Fig. 3 shows the HRES configurations assessed in this study.

### *2.2. Model Inputs*

#### *2.2.1. Site description and load estimation*

In this study, the Hapcheon Dam, an artificial dam with a total storage volume of 900,000 $m^3$, located in Gyeongsang-do, South Korea, is selected as a research area. Geographical location of this lake is 35° 31' 26" N / 128° 1' 7" E, located in the Hwang River. It is constructed by the Korean public water resources corporation 'K-water'. Hapcheon Lake possesses floating PV system which generate electricity above the water. FPV system installed in the dam is under the extension work, possible to generate electricity with 41MW power after the construction expected for completion on December, 2021. Utilizing this large scale electricity generation, this study aim to investigate the feasibility of large scale off-grid power. The annual target electrical load selected in the research is 70GWh, an annual electricity consumption of Ulleung island at a scale of 1:4, which is equivalent to 1/80 of it on Jeju island, the biggest island on South Korea.

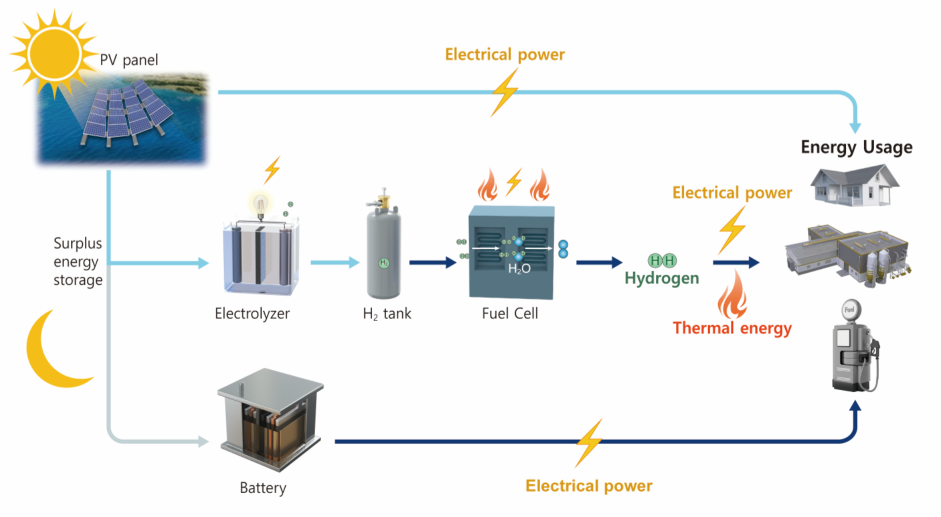


Figure 1: Schematicof the stand-alone hybrid renewable energy system

The target electricity load data is obtained from open-source data provided by KPX (Korea Power Exchange). The loads include domestic, public consumption and commercial usages. (Figure 4) shows the annual load profile of the area under study with a peak of 3,152 kW; the average load is 2,019 kWh with a load factor of 0.64. It shows periodic load increase in summer and winter owing to the increase of electricity consumption to cool down the indoor temperature or provide warmth inside the buildings.

### *2.2.2. Metrological data*

Solar irradiation and the ambient temperature of the solar cell are the major cause of change in average panel conversion efficiency. Reflecting such metrological approach, HOMER calculates monthly variation of electricity generation by PV system as a function of the monthly average solar global horizon irradiance and the monthly average temperature data. (Figure 5) presents the average daily radiation (kWh/m$^2$/day) and daily temperature. K-water provided the solar irradia-

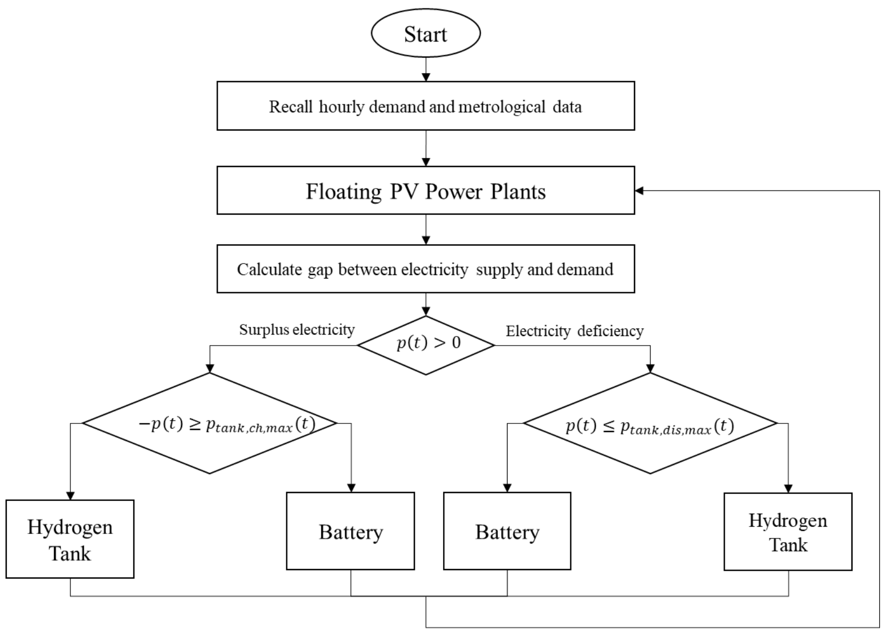


Figure 2: Dispatchstrategy of the PV/FC/Battery hybrid renewable energy system

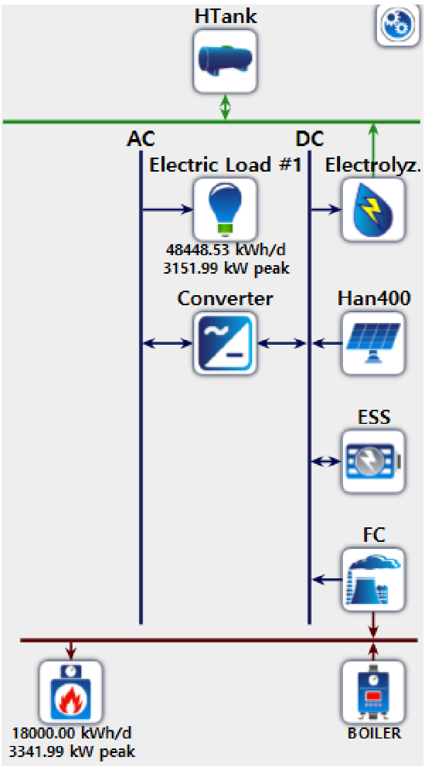


Figure 3: Designof hybrid renewable energy generation system by HOMER software

tion and the ambient temperature data measured from Hapcheon Lake. The measurement period of the data is from January 1 to December 31, 2020 with one-hour unit. Affected by seasonal change, the peak of solar radiation (6.809 kWh/m$^2$/day) and temperature (33.87 °C) appears in summer. The lowest point appears in December at 2.2 kWh/m$^2$/day and 6.95 °C.

## 3. System Reliability assessment criteria

Feasibility and performance analysis of entire stand-alone system is very essential to suggest an optimal configuration in the HRES. The optimization has been carried out in HOMER environment. In this study, finding the optimal configuration of the HRES system is based on minimizing the LCOE and system reliability drawback (LPSP) (%) with payback period.

The price of generating electricity per kWh of useful electrical energy is defined as Levelized Cost of Energy (COE). The LCOE is computed by dividing the annualized cost of producing electricity by the total annual electricity load served which is defined as follows (Garni et al., 2018):

$$LCOE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}} \tag{1}$$

where $C_{ann,tot}$ is the total annualized cost, $E_{served}$ is the total electrical load served.

The second term in the numerator means the annualized cost caused by boiler to serve thermal load. In this system, this term is zero since the boiler does not operate to serve a thermal load. Total annualized cost of electricity is given as Eq. 2 and where, $C_{NPC,tot}$ is the total net present cost (NPC), $CRF$ is the capital recovery factor function, $i$ represents the annual real discount rate, $R_{proj}$ is the project lifetime.

$$C_{ann,tot} = C_{NPC,tot} \times CRF\left(i, R_{proj}\right) \tag{2}$$

CRF is calculated using Eq. (3).

$$CRF\left(i, R_{proj}\right) = \frac{i(1+i)^{R_{proj}}}{(1+i)^{R_{proj}} - 1} \tag{3}$$

The loss of power supply probability (LPSP) is reliability index used in this paper to assess insufficient power supply which is characterized by a number of zero and one. An LPSP of zero represents that the required load will always be satisfied, and an LPSP of one implies that the load won't be able to be provided in any case. To calculate the LPSP of the HRES, the following equations has been introduced:

$$LPSP = \frac{\sum_{t=1}^{T} P_{deficit}(t) \times \triangle t}{\sum_{t=1}^{T} P_{demand}(t) \times \triangle t},\ T = 8760 \tag{4}$$

Without connecting grid to the HRES, this study aims to assess the feasibility of stand-alone renewable power lant. To discuss the feasibility, payback period and thermal revenue is considered.

Payback period is an index refers to the amount of time the system takes to recover the cost of an investment (Koussa et al. (2014)). The payback period $n_p$ is given as following Eq. 7:

$$n_p = ln\left(\frac{i \times P}{AS} + 1\right) / ln(1+i) \tag{5}$$

where $AS$ is annual saving, $j$ is year, $i$ is interest rate, and $P$ is capital cost.

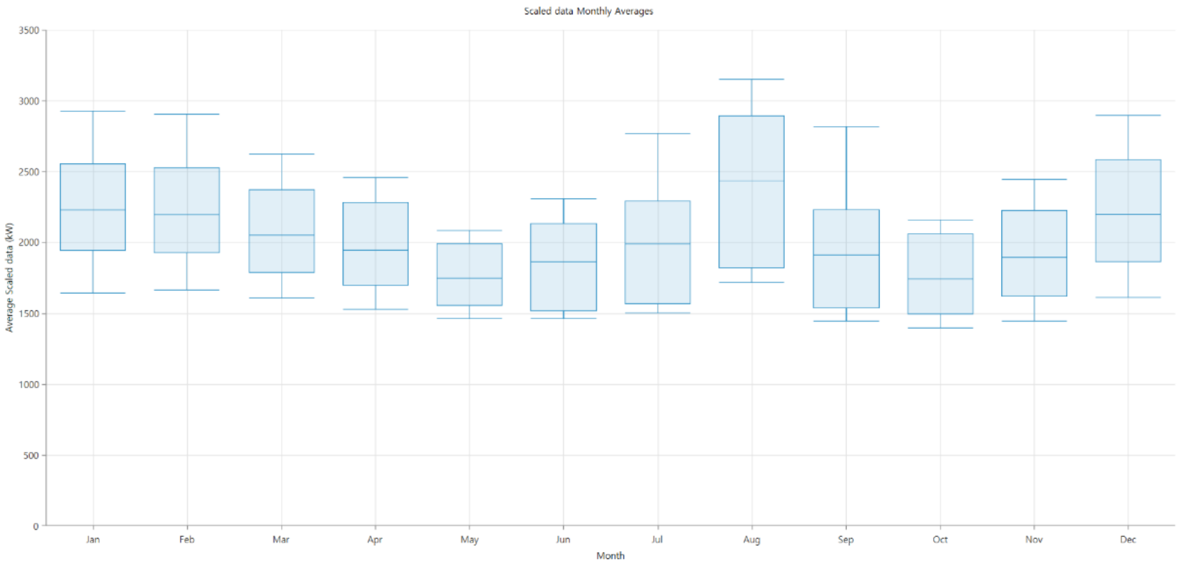


Figure 4: Annualone hour-unit electricity load profiles

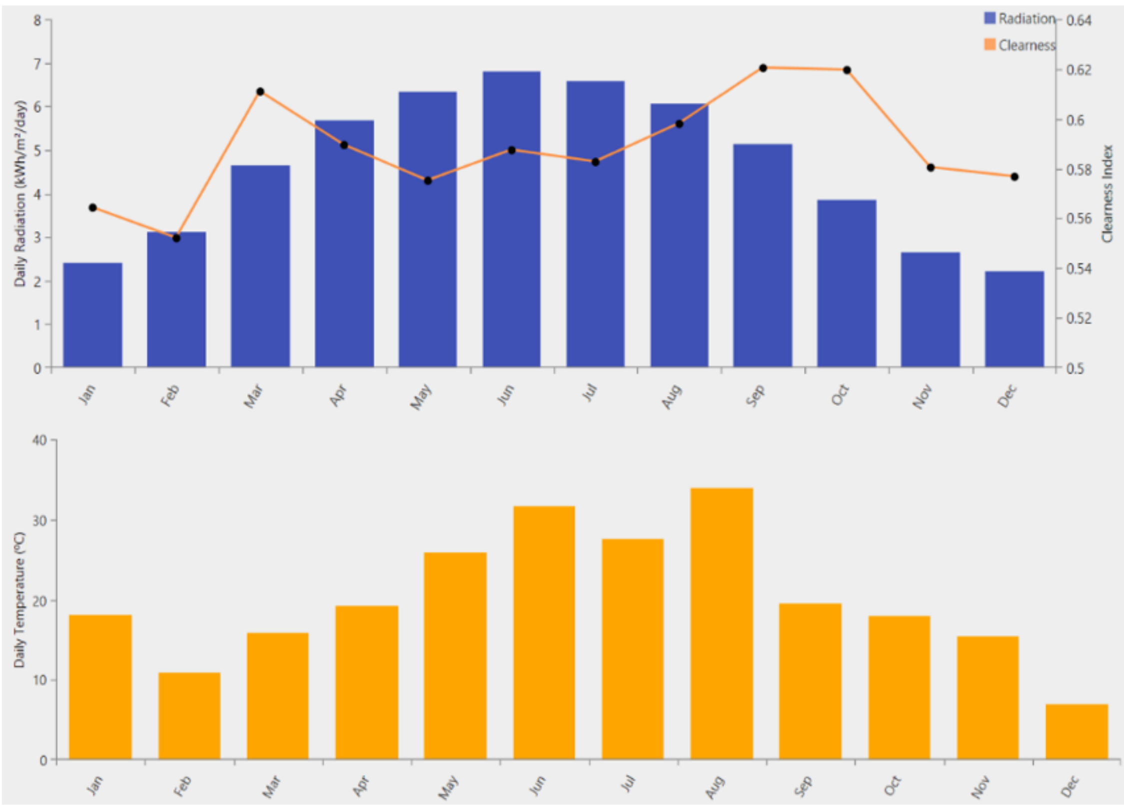


Figure 5: Hourly metrological data during a year in Hapcheon

The advantage of power system using hydrogen as an energy storage medium is that the power system produces considerable amount of thermal energy by fuel cell generator not only to storage large scale energy. In combined heat and power (CHP) systems, if thermal energy generated by the fuel cell is captured and put to use, additional energy efficiency increases by 40-45%. The annual thermal revenue $AR_{thermal}$ of HRES is estimated by:

$$AR_{thermal} = \sum_{n=1}^{8760} E_{FC} \times c_{thermal} \tag{6}$$

where $\sum E_{FC}$ is annual thermal energy generation by fuel cell and $c_{thermal}$ is the trade price of thermal energy.

As a renewable energy power plant, assessing the amount of GHG emissions during the project lifetime should be conducted to find out the advantage of the system compared to grey hydrogen-based fuel cell plant. The load connected to the grey hydrogen-based fuel cell is a baseline instance in comparing the GHG emission with the HRES. The method of calculating the gap of total amount of GHG emission between two concept of power plants is suggested as following equation.

$$System_{CO_2} = \sum_{t=1}^{8760} P_{pv}(t) \times e_{pv} \tag{7}$$

where $System_{CO_2}$ is total amount of $CO_2$ emissions by HRES, $P_{pv}$ is $e_{pv} = 0.045$ is $CO_2$ emission rate for mono-Si PV (Peng et al. (2013)).

$$Base_{CO_2} = NFC_{grey} \times k_{carbon} \tag{8}$$

where $Base_{CO_2}$ is total amount of $CO_2$ emissions by grey hydrogen-based fuel cell, $NFC_{grey}$ meeans Net Fuel Consumption of grey hydrogen, and $k_{carbon}$ represents carbon content of grey hydrogen as a percentage of its mass.

The total $CO_2$ emission reduction by the HRES is calculated as following equation:

$$tCO_{2saving} = Base_{CO_2} - System_{CO_2} \tag{9}$$

## 4. Result and discussion

### 4.1. Comparison of stand-alone HRES with ESS and without ESS

For optimization and analysis for this paper, the overall input economic and technical data for the optimization are summarized in Table 1. Optimization results from HOMER software has been discussed to determine which renewable power system is most effective. The simulation was performed for the two scenarios of stand-alone HRES using battery and without using battery, shown in Figure 6.

As a reference case, the scenario of HRES of FPV system and fuel cell with hydrogen tank has been considered. In this case, hourly excessive electricity generated from Q.PEAK DUO Poseidon units of FPV has been stored on hydrogen tank to supply insufficient energy after the sun goes down. It is found from Figure 6 that as the LPSP increases, the LCOE decreases. In the case of HRES without using battery at LPSP of 5%, total NPC from HRES was estimated at approximately \$53.0 million and LCOE was estimated at approximately \$0.201 over the project lifetime. In comparison, it recorded total NPC of approximately \$32.1 million and LCOE of \$0.119 over the project lifetime in the case of HRES with battery. The annual served load and power generation output is shown in figure 7 and figure 8. Power generation output by floating PV fluctuates from 0 kW (no electricity production) to 39 MW, with 164.4 MWh/d. average output which outperforms the average load demand of 48.4 MWh/d (average hourly load demand of 2020 kW).

According to Figure 9, fuel cell cost reports major portion in entire system cost which affects economic feasibility of the large scale power plant project. This connotes that the technological and economical improve in fuel cell efficiency may determine whether widespread adoption of the proposed hybrid renewable energy system is possible or not. To discuss this impact, sensitivity analysis of fuel efficiency of fuel cell has been conducted, shown in Fig. 10, indicating that the HRES with fuel efficiency of 0.04 kg/hr/kW is 18.2% more profitable.

The optimization result confirmed that HRES of floating PV system and fuel cell with combined energy storage system of hydrogen tank and VRBs can sufficiently produce large scale electricity with lower LCOE compared to the reference case, as shown in Figure 6. At LPSP 5%, total

Table 1: Economic and Technical input parameters for the optimization of HRES

| | | | |
|---|---|---|---|
| **FPV** | | **Fuel Cell Generator** | |
| **Factors** | **Value** | **Factors** | **Value** |
| Size | 41 MW | Type | PAFC |
| Capital cost | \$36/kW | Brand name | Doosan PureCell |
| Replacement cost | \$30/kW | Size | 4400kW |
| O & M cost | \$5/kW/year | Capital cost | \$3000/kW |
| Temperature co-efficient | -0.394/C | Replacement cost | \$3000/kW |
| Derating factor | 85% | O & M cost | \$1/kW/hour |
| Operation temperature | 45.5C | CHP Efficiency | 90% |
| Vanadium Flow Redox Battery | | Lifetime | 40,000 hours |
| **Factors** | **Value** | Minimum load ratio | 20% |
| Model | FB 250-2000 | Electrolyzer | |
| Nonimal voltage | 700V | **Factors** | **Value** |
| Capacity | 2480kWh | Capital cost | \$500/kW |
| Capital cost | \$347/kWh | Replacement cost | \$250/kW |
| Replacement cost | \$347/kWh | O & M cost | \$10/year/kW |
| Bidirectional Converter | | Lifetime | 15 years |
| **Factors** | **Value** | Efficiency | 85% |
| Size (Optimization) | 1000~1000kW | Hydrogen Tank | |
| Capital cost | \$300/kW | **Factors** | **Value** |
| Replacement cost | \$300/kW | Capital cost | \$500/kW |
| Lifetime | 15 years | Replacement cost | \$500/kW |
| Efficiency | 95% | Lifetime | 25 years |

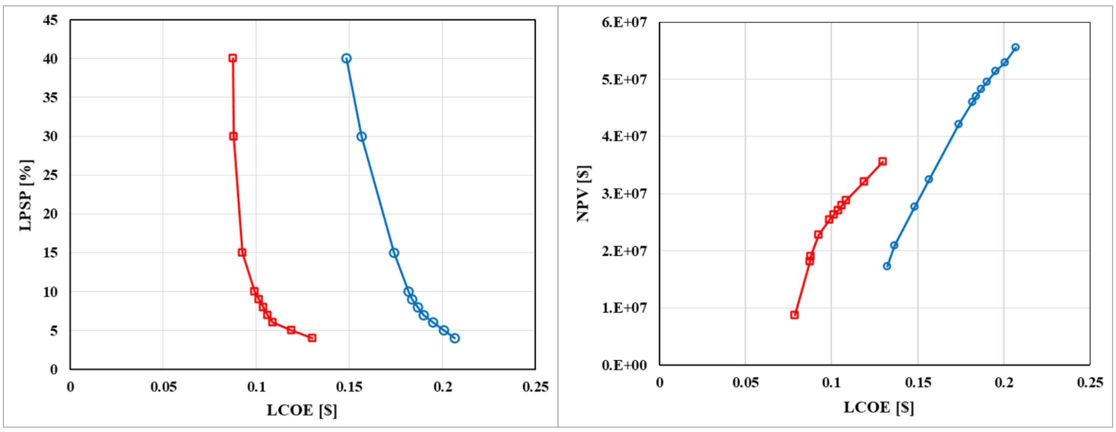


Figure 6: LPSP and LCOE profile of optimized FPV based hybrid renewable energy systems: withbattery system and without

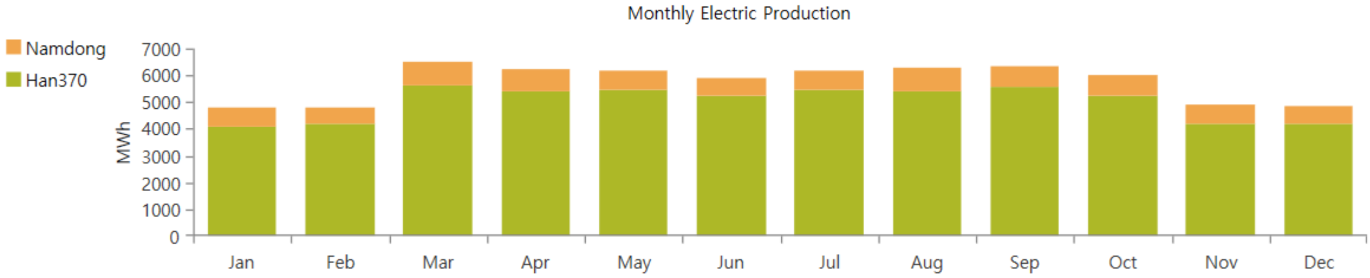


Figure 7: Monthlypower output from Q.PEAK DUO Poseidon units of FPV to generate total annualoutput of 17.8 GWh, simulated in a reference case with no VRBs

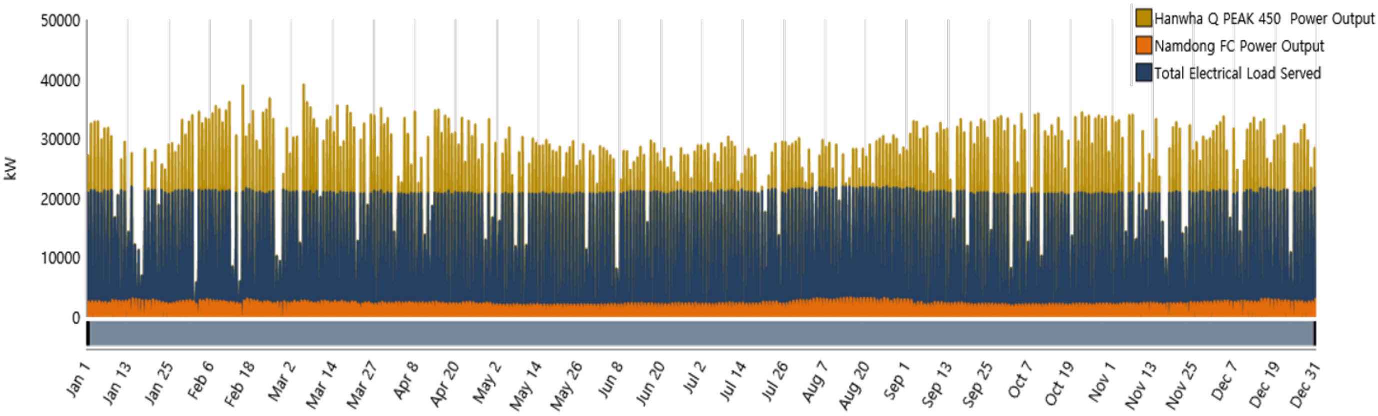


Figure 8: Optimizedpower output of floating PV/hydrogen fuel cell/total load served data, simulated in a reference case with no VRBs

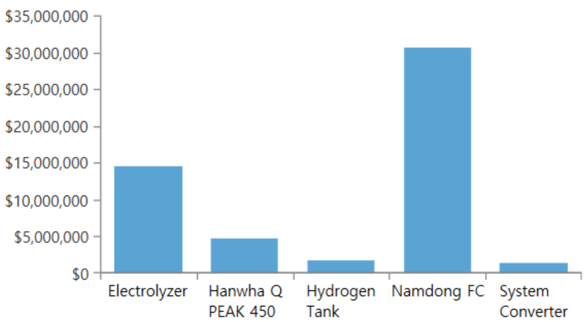


Figure 9: Componentcosts calculated by the simulation in a reference case with no VRBs

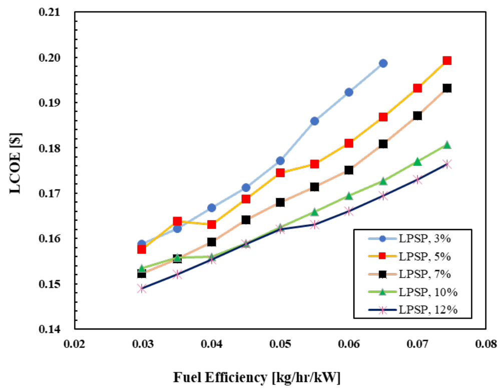


Figure 10: Sensitivityanalysis of fuel efficiency in optimized HRES

NPC from HRES was estimated at approximately $32.1 million and LCOE was estimated at approximately $0.119 over the project lifetime. In this case, some part of hydrogen storage was substituted with VRBs that decreased the high-priced operation cost of fuel cell into battery system. These results show a decrease in net cost with minimizing energy shortage problems. This result implies that the system associated with batteries prevents energy loss on the process of hydrogen storge which improve supply stability and provides electricity in lower cost. Figure 11. shows that approximately over 50% of total eletric load served by HRES met the average load demand of

2020 kW during the year.

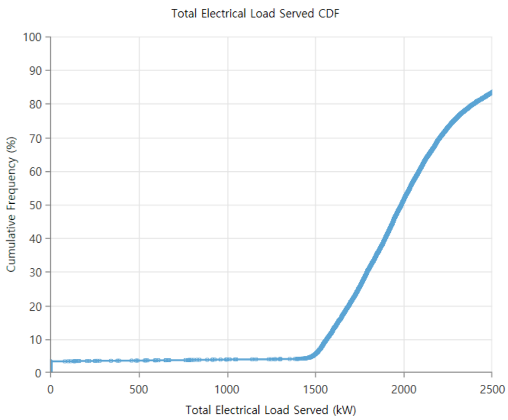


Figure 11: Annualcumulative frequency of total electrical load output served by HRES

### *4.2. Case study: 41 MW FPV/FC/VRB Hybrid System for Independent Operation of 16 9 GWh Site*

In this section, we consider profitability and feasibility of the best solution of optimized hybrid renewable energy system (HRES) shown in Table 2. The proposed power system based on FPV and fuel cell has considerable benefits on large scale power generation with utilizing additional thermal energy, reducing GHG emissions, and financial gain by the conservation of land cost by employing FPV system. From Table 2, electricity production of 16.9 GWh costs $35.6 million for the entire project period at LCOE of $0.1337. However, if electricity is generated by 32% improved fuel cell than the present case, the NPC would decrease by $1.70 million. The floating PV-fuel cell combined hybrid system generating 16.9 GWh would reduce GHG emissions by up to 48.7 kt compared to grey hydrogen-based power plants every year. As the government around the world sets continuously higher price that emitters must pay for GHG emissions they emit, adoption of HRES proposed in this paper will live up to the high standards of global GHG emission policy. Considering KRW 30,000 (about $25)/t$CO_2$ as a conservative carbon tax rate on electricity produced from fossil fuels in South Korea(Peng et al. (2013); Shin (2010)), relative profitability of $1.22 million from the reduction of carbon dioxide by 48.7 kt every year strengthens the advantage of proposed HRES. Furthermore, FPV system offers further opportunity to save land rent by installing PV modules in lake rather inland implementation.

According to the Criteria for Permission to Occupy and Use Rivers in South Korea, the rent in Hapcheon Dam installing floating PV systems is $1600/acre corresponding to 1.5% of average rent of inland PV system installation. As considerable gap between inland rent and overland rent, our proposed HRES generates $11.3 million of annual savings (approximately 31.7% of NPC) from total site area of 108 acre in Hapcheon which is represented in Table 2. Another advantage of our HRES using hydrogen as an energy storage medium is scalability and stability. Besides, hydrogen generates both electrical power and thermal energy at the same time due to the characteristic of fuel cell. The amount of annual thermal energy generation by the proposed system is 2.32 GWh, and by multiplying this data with 0.045 $/KWh of average thermal energy cost in South Korea, the system generates further $1.04 million of annual revenue. Supported by these results, the proposed system possesses profitability that the customers are able to use electricity with low cost.

## 5. Conclusion

In this study, we evaluated optimized HRES in respect of stable supply and financial benefit without shortage. We used floating PV modules as a major power generation medium with given 2020 metrological data measured by K-water at Hapcheon Lake, South Korea. We used PAFC fuel cell model data of 4MW power capacity for auxiliary power supply, currently installed and operating by the Korea South-East Power Co. at Bundang-gu, South Korea. KPX provided hourly electrical energy consumption data in Jeju-island, and we processed the data to evaluate the feasibility of stable stand-alone power system for independent island. The performance of the HRES was simulated for average loads of electricity at 2,020kW. The NPCs of the optimized power

Table 2: Optimized result and analysis data of HRES at an optimal point

| | | | |
|---|---|---|---|
| LPSP | 5% | Factors | Value |
| Factors | Value | Lant cost for overland PV | 106,000$/acreue |
| FPV | 41MW | Lant cost for floating PV | 1,600$/acre |
| Fuel Cell | 4400kW | Floating PV system site area | 108acre |
| VRBs | 12units | Present land rent for overland PV | \$11.5M |
| Htank | 1200kg | Present land rent for floating PV | \$173,000 |
| Converter | 2979kW | Relative Annual Saving from floating PV | \$11.3M |
| LCOE | \$0.1337 | Thermal Energy Production from FC | 2.32GWh |
| NPC | \$35.6M | Thermal Energy Cost | \$0.045/kWh |
| Total Electricity Consumption | 16.9GWh | Annual Revenue for Excessive Thermal Energy | \$104,000 |

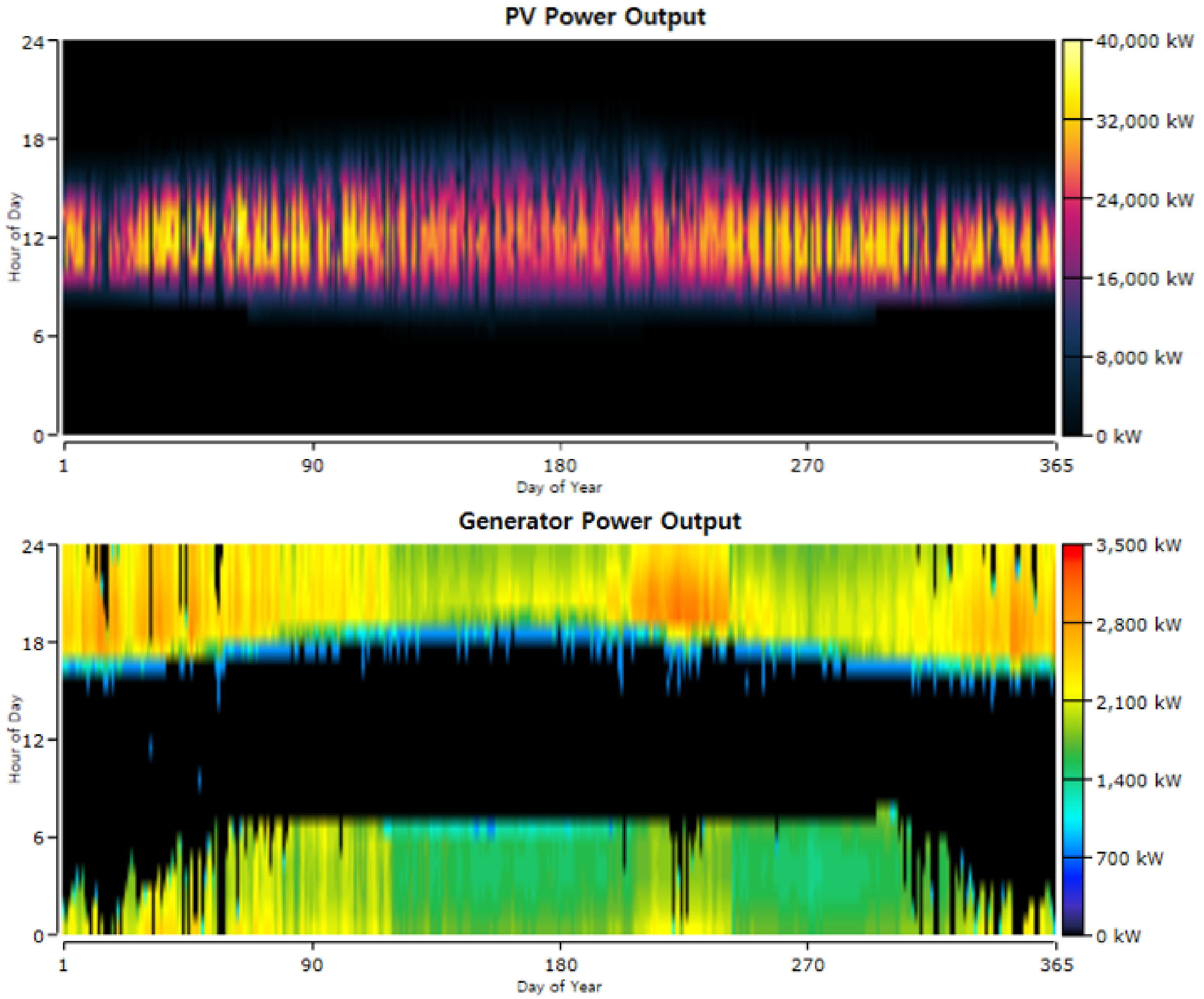


Figure 12: Powergeneration output by floating PV and fuel cell throughout the year and daytime

plant have been compared under the assumption of 25 years of the project period. This simulation confirmed that utilizing VRBs with hydrogen tank effectively eliminates electric power shortages, increasing the feasibility of the designed system. The battery/hydrogen tank combined storage system outperformed the hydrogen tank storage system, with decrease of LCOE by about 41%. The discrepancy between the two designed HRES maintained as the electricity load changed from 48.4 MWh/day to 96.9MWh/day. This output results from the difference between battery and hydrogen tank as an energy storage medium. By combining two energy storage system and finding the optimal design of the system, the proposed HRES possess each advantage of the two energy storage method. Fig. 12 shows the power generation output of optimized HRES combining hydrogen tank and battery both. Fuel cell generator accounts for the largest part of entire cost and improving economical and fuel-effective generator is at the priority to encourage global adoption of the HRES. If fuel efficiency of the fuel cell increases by 46%, then our HRES is possible to lower the price of electricity by 18%. To find the best solution of HRES which generates green electricity with lowest LCOE, the optimization process has been conducted and the result is shown in Table 2. At the best case of HRES to supply interrupted load demand, the LCOE is $0.1337 in LPSP of 5%, the GHS emissions saving compared to grey hydrogen based generator is 48.7 kt, corresponding to $1.22 million of carbon tax expected to be charged in South Korea, relative annual saving from floating PV of $11.3 million, and annual revenue for excessive thermal energy of $0.104 million. Influence of cost saving associated with land and fuel cell generator would continue to increase as numerous eco-friendly policies are carried out.

## References


Choi, Y.-K. (2014). A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact. *International Journal of Software Engineering and its Applications*, 8, 75–84.

Council, H. (2017). How Hydrogen Empowers the Energy Transition.

Cozzi, L. (2020). World Energy Outlook 2020. *International Energy Agency.*

Garni, A., Hassan, Z., Awasthi, A., & Ramli (2018). Optimal design and analysis of grid-connected photovoltaic under different tracking systems using HOMER. *Energy conversion and management*, 155, 42–57.

Koussa, D., Saheb, M., & Koussa (2014). HOMER analysis for integrating wind energy into the grid in southern of Algeria. *International Renewable and Sustainable Energy Conference (IRSEC).*

Li, Z. (2019). Integrating a redox flow battery into a Z-scheme water splitting system for enhancing the solar energy conversion efficiency. *Energy & Environmental Science*, 12, 631–639.

Ma, S. (2021). Fuel cell-battery hybrid systems for mobility and off-grid applications: A review. *Renewable and Sustainable Energy Reviews*, 135, 110119–110119.

Park & Sangwook (2019). Profitable production of stable electrical power using wind-battery hybrid power systems: A case study from Mt. Taegi, South Korea. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 6, 919–930.

Peng, J., Lu, L., & Yang, H. (2013). Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. *Renewable and sustainable energy reviews*, 19, 255–274.

Perez, M. (2018). Deploying effectively dispatchable PV on reservoirs: Comparing floating PV to other renewable technologies. *Solar Energy*, 174, 837–847.

Rad, M. A. & Vaziri (2020). Techno-economic analysis of a hybrid power system based on the cost-effective hydrogen production method for rural electrification, a case study in Iran. *Energy*, 190, 116421–116421.

Shin, S. (2010). An Assessment of the Feasibility of the Carbon Tax in Korea. *Korea Environmental Policy Bulletin*, pages 1–199.

Temiz, M. & Javani, N. (2020). Design and analysis of a combined floating photovoltaic system for electricity and hydrogen production. *International Journal of Hydrogen Energy*, 45, 3457–3469.