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Feasibility analysis of off-grid hydrogen energy storage system for energy independent island in south Korea

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Abstract

Human beings are facing the great challenges of global warming and energy depletion, so many countries are making aggressive policies to solve the energy crisis and climate change.
The south Korea government has been promoting active policy supports for the development of renewable energy and actively fulfill the Paris Climate Change Accord to reduce carbon emissions. The aim is to increase renewable energy from 7% to 20% of the total generated energy and reduce carbon dioxide emissions by 37% of BAU value in South Korea by 2030. With the policy stimulation, Renewable energy sources have been greatly developed, especially large-scale solar, wind and hydro power plant. However, diesel engine power generation system is still widely used in many islands which is far from land. In these islands, the transportation supply of fuel is influenced by transport costs and fuel price fluctuation, also limited by weather factors. Furthermore, diesel power generation increase carbon dioxide emissions and pollutes the environment. In this study, hydrogen energy power generation system was studied for offering a zero-emission solution with renewable energy source in Gageodo Island. This system consisted PV panel, wind turbine, li-ion battery, three-phase converter, PEM water electrolysis, DI water generator, hydrogen storage tank and PEMFC. To determine the feasibility of the entire system, Homer software was used for optimization design and economic analysis.

Introduction

Resource depletion, climate change and growing energy demand caused by fossil fuel emissions, the world has been focusing on the alternative energy sources that can replace fossil fuels [1], [2], [3]. The alternative energy sources for fossil fuels are biofuels, hydrogen, solar, geothermal, wind energy, hydro-power and so on. In these alternative energies, solar, wind, hydropower and biomass energy accounts for the highest proportion 74% in the total renewable energy use in South Korean by government policy support [4]. Even so, diesel power plants are still being used for many islands in South Korea. According to the statistics of KEPCO in 2012, There are still 63 islands that are powered by diesel power plants and it reported the status and deficits of the diesel power plants in island. It shows most of the diesel power plants are in a state of oversupply, the annual loss of these power plants is as high as million won [5]. To lowing the deficits of these diesel power plants and also reduce the carbon dioxide emission, a solution of HESS (hydrogen energy storage system) for green energy generation need to be developed. Only using solar and wind energy to generate electric power, both two have irregular electric power generation characteristics and the power output are heavily affected by the solar illumination index and wind speed therefore energy storage system is indispensable [6]. The device of energy storage system usually uses accumulator or battery, but these devices cannot store electric power for long time and the replacement costs of batteries are very expensive. In order to solve these problems, hydrogen energy storage system has been put forward in this project for giving a solution for continuous system which can provide extremely clean, stable power generation. Hydrogen, what is known is it can be produced by electrolysis using water. In this project, electrolysis produces clean hydrogen using renewable energy solar and wind turbine then the clean hydrogen is provided to the PEMFC to produce green electricity for providing electric to Gageodo Island in South Korea. Homer software was used to determine the entire system, the results are focused on the system optimization, electric production and carbon emission.

1. Scientific Approach

Optimize system and economic analysis is crucial for decision-design and improving design using Homer software. Many of studies on the renewable energy system in different countries. Abolfazl Shiroudi analyzed Technical-economic assessments for PV-Electrolyser-Fuel cell energy system at the Taleghan site in Iron in 2011, The results shows that the total net present cost (NPC) is around $115,034 and cost of energy (COE) of the proposed hydrogen system is $1.216/kWh [7]. Getachew Bekele studied feasibility of small-scale Hydro/PV/Wind based hybrid electric supply system in Ethiopia in 2011, as a final result, the cost of energy less than $0.16/kWh [8]. Abolfazl Shiroudi analyzed optimization and technoeconomic for Stand-alone PV-hydrogen energy system in Taleghan-Iran in 2013. The total initial capital cost, net present cost, and cost of electricity produced from this energy system are $193,563, $237,509 and $3.35/kWh, respectively [9]. Omar Hazem Mohammed studied the optimal design of a stand-alone hybrid PV/FC power system without battery storage in the city of Brest, Western Brittany in France in 2014, for the optimal design hybrid power system TNPC is $8,942,636 while its capital cost and cost of energy (COE) are $4,197,750, $0.12/kWh [10]. Kenneth E. Okedu are studied off grid micro system consisting of diesel generation, biogas, solar PV, wind turbine, micro-hydrogen plants and DC generator of fuel cell for five different renewable energy penetrations in Al-Zahia-Musandam of Oman in 2016, the results show that the optimize design for the NPC is $515,746 and COE is $0.47/kWh [11]. Anand Singh analyzed a solar PV, fuel cell and biomass gasifier hybrid energy system in Indian in 2016.

It has been found the COE is Rs 15.064/kWh and complete net present cost Rs 51,89,003 [12]. Tania Khadem studied hydrogen fuel cell system for irrigation in Bangladesh in 2017, the system is composed of PV array, electrolyser, hydrogen tank, fuel cell and DC pump. The results show that Per kg cost of hydrogen (COH) is $9.35 [13]. Himadry Shekhar Das studied the feasibility of hybrid renewable energy systems (photovoltaic arrays, batteries, and fuel cells) in Sarawak, East Malaysia in 2017, the results showed that the cost of electricity was $0.323/kWh [14]. Shoeleh Vahdatpour analyzed the potential of using a hybrid solar cell/wind turbine/biomass system for supplying the electricity demands of a residential building of Iran in 2018, climates (Total net present cost (NPC) and cost of electricity (COE) are $11,639 and $1.808/kWh) [15].
In line with the above research, even though many countries gave studies on Techno economic analysis for solar PV-hydrogen-FC renewable energy system, but there are few researches in South Korea for energy independent island. Therefore, the solar PV/wind-hydrogen-PEMFC renewable energy systems were studied for feasibility analysis in Gageodo Island using Homer software. The main components of the systems are shown in Figure 1.

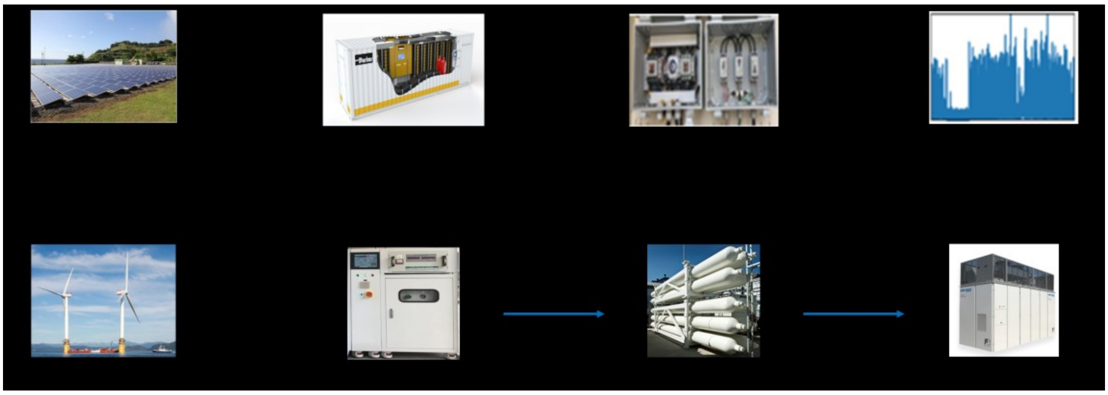

Figure 1: Main components of the hydrogen energy storage power generation system

2. Simulations

Study area

Gageodo island is far from mainland and located in southern region, South Korea (34º03' N, 125º07' E) as Figure 2 shows. There are 323 households in Gageodo Island. The reason for chosen this island is that diesel power plant is still being used. Currently three 250kW diesel engines and one 300kW diesel engine are alternately in operation and there are big losses every year due to electric over supply. Besides environmental pollution and carbon dioxide emissions are another reason which we considered.

Figure 2: Map of study area

Electric demand

In this study, the most important objective was to assess whether the system's power resources could meet the load requirements. The scaled annual average of electric demand is 5,383kWh/day.

Solar source

The important factor of solar radiation data is needed to be provided for modeling solar PV system using HOMER software to calculate power generation. The solar radiation data input is based on solar source data from the NASA surface meteorology and solar energy from HOMER software in this study. The grid coordinates input to the HOMER is 34º03' N, 125º07' E of Gageodo Island. The annual average of solar average is 4.08 kWh/m^2/day and 5.88 kWh/m^2/day as shown in Fig. 3.

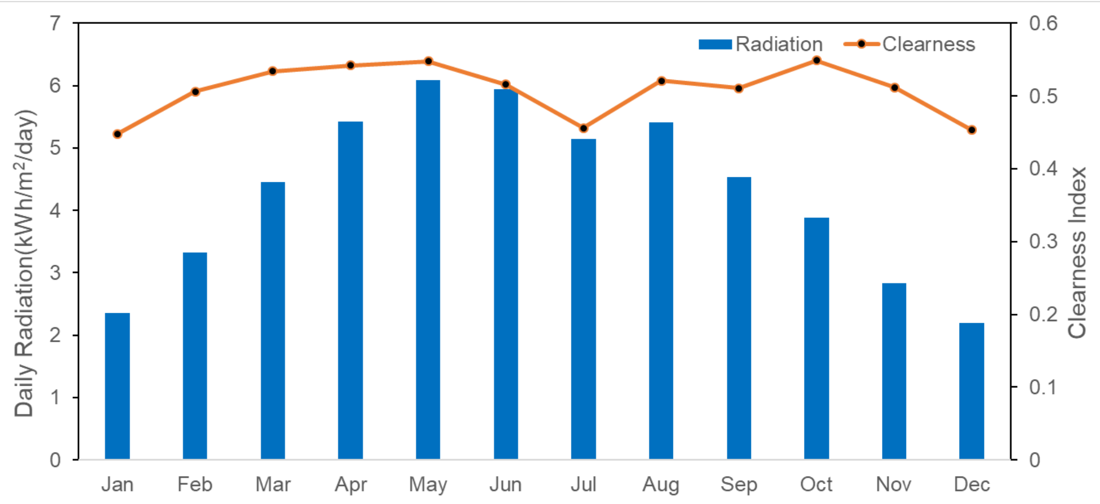

Figure 3: Solar source data at Gageodo Island

Wind Source

The wind turbine is scheduled to install in this solar PV-hydrogen-FC renewable energy system. Therefore, it needs to input wind resource data to HOMER with the grid coordinates of our site selection. The wind speeds are shown as Figure 4. at an anemometer height of 31.8 m Which provided by the NASA surface meteorology and Solar energy of HOMER software. The annual average of wind speed is 6.71m/s as shown in Fig. 4.

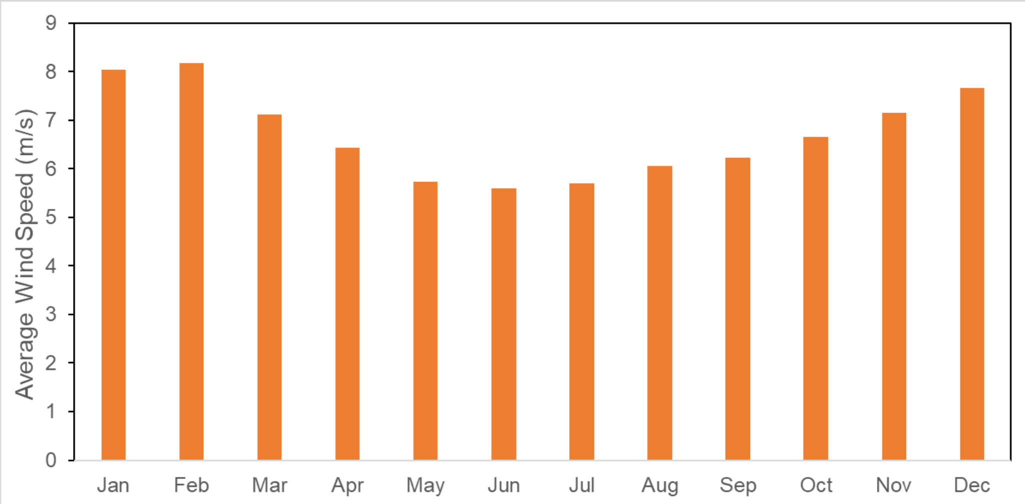

Figure 4: Wind source data at Gageodo Island

Li-ion battery bank

Due to the fluctuation and insufficient certainty of renewable electricity generation (solar/wind energy), battery banks need to be used as energy storage system. Wind turbine is alternating current, it needs to be stored in direct current. The battery bank has consisted of 100kWh battery models with 600V, 167 Ah. The round trip of the battery bank is 90%.

Converter

In this study, the solar and wind energy is stored as direct current with battery bank. But the power supply of electrolyser is three-phase AC. Therefore, the three-phase invertor is need to convert one-phase DC to three-phase AC. The efficiently of invertor is 85% as we installed.

PEMWE

Electrical energy which was provided from solar and wind need to be produced as hydrogen energy. PEM electrolyser as its simplicity and high efficiency and simplicity was selected as hydrogen production system integrating with renewable energy system.

Hydrogen storage tank

The hydrogen which is produced by PEMWE need to be stored for PEMFC electricity production. In this study, Hydrogen production was calculated from PEMWE. The hydrogen gas is stored as 30 bar in the high-pressure hydrogen storage tank for high energy density.

PEMFC

The hydrogen which stored in the tank is used to supply PEMFC for electricity production. PEMFC generate electricity by a chemical reaction. PEMFC can continuously generate electricity as long as hydrogen is supplied. The PEMFC system is composed of fell cell stack, blower, humidifier, reformer, water reservoir, cooling pump.

Feasibility analysis

HOMER is applicable to feasibility analysis for economic analysis and optimization design for overall system. As the load demand, the PEMFC is simulated as 400, 500, 600 kW and the PEMWE is simulated as 450, 500, 550, 600, 650 kW. Solar PV, wind turbine, battery, converter is simulated as HOMER optimizer. The economic descriptions of all of components are shown in Table 1. The important metrics for the entire system are COE and NPC. The COE is the most important economic output for measuring the economic value. The NPC is the results to calculate the overall system cost.

Table 1: Input data on option costs, sizing and other parameters

Components	Capital ($/kW)	Replacement ($/kW)	O&M ($/kW/year)	Life time (year)	Capacity
Solar PV	1,800	1,800	25	20	Homer optimizer
Wind turbine	2,900	2,500	40	25	Homer optimizer
li-ion battery	146.875	146.875	0.1	15	Homer optimizer
PEMWE	1,345	1,000	20	15	450, 500, 550, 600, 650 [kW]
H2 tank(kg)	1,300	1,200	15	25	1,000,1,100, 1,200,1,300 [kg]
PEMFC	8,300	4,000	0.02	15	400,500,600 [kW]
Converter	800	750	150	15	Homer optimizer

3. Results

The system is composed of solar PV, wind turbine, battery, three-phase converter, PEMWE, hydrogen tank and PEMFC as shown in Fig.5. The Feasibility analysis of off-grid hydrogen energy storage system focus on the capacity design and economic evaluation. The capacity of PEMFC, hydrogen tank and PEMWE was designed as Table 1. Solar PV, wind turbine, battery, converter was simulated by Homer optimizer. There are 604,282 solutions were simulated, 581,939 were feasible to the load demand.

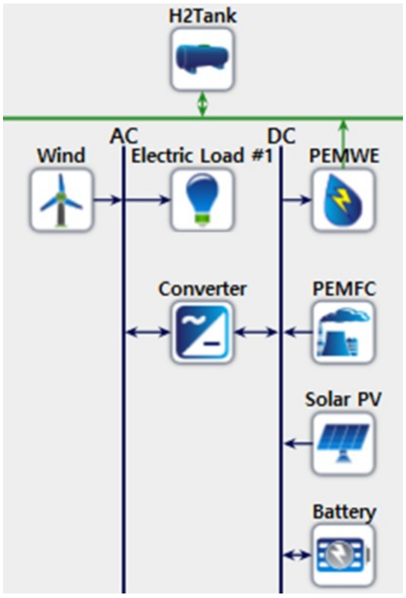

Figure 5: HOMER simulation model

The electricity production and quantity of system components are presented in Table 2. It can be seen that the power production of the solar PV is 900,338 kWh/year, wind turbine power production is 797,411 kWh/year and PEMFC power production is 35,015 kWh/year. Excess electricity is 58,987kWh/year with 1.48% unmet electrical load.
The Table 3, Table 4 shows the capital cost, replacement cost, O&M cost and total cost of the individual components for one year and for a lifetime of 25 years of the entire system.

The capital cost of simulation results is $10,872,750. The cost of PEMFC and li-ion battery bank are highest in total capital cost of the overall system.

Table 2: Electrical production and quantity of component in the system

Components	Production (kWh/year)	Fraction
Solar PV	900,338	52%
Wind turbine	797,411	46%
PEMFC	35,015	2%
Total	1,732,764	100%

Quantity	Value	Unit
Excess electricity	58,987	kWh/year
Unmet load	13,092	kWh/year
Renewable Fraction	100	%

Table 3: Annualized costs of the system ($/year)

Components	Capital	Replacement	O&M	Salvage	Total
Solar PV	85,701.24	39,707.57	18,750	-24,570.05	119,588.76
Wind turbine	73,639.59	0	16,000	0	89,639.59
li-ion battery	186,479.56	104,723.91	200	-23,761.16	267,642.30
PEMWE	38,422.72	16,042.81	4,500	-3,640.01	55,325.53
Hydrogen tank	82,527.12	0	1,000	0	83,527.12
PEMFC	210,761.58	0	2,800	-16,177.81	197,383.77
Converter	12,696.48	6,684.50	3,750	-1,516.67	21,614.32
System	690,228.30	167,158.79	47,000	-69,665.70	835,721.38

Table 4: Total net present cost of the system ($)

Components	Capital	Replacement	O&M	Salvage	Total
Solar PV	1,350,000	625,489.32	295,357.44	-387,037.19	1,883,809.57
Wind turbine	1,160,000	0	252,038.25	0	1,412,038.35
li-ion battery	2,937,500	1,649,652.51	3,150.48	-374,295.22	4,216,007.77
PEMWE	605,250	252,712.73	70,885.79	-57,338.84	871,509.67
Hydrogen tank	1,300,000	0	15,752.40	0	1,315,752.40

PEMFC	3,320,000	0	44,106.71	-254,839.30	3,109,267.41
Converter	200,000	105,296.97	59,071.49	-23,891.18	340,477.27
System	10,872,750	2,633,151.53	1,031,781.99	-1,097,401.74	13,440,281.78

4. Conclusion

This paper investigated the simulation of optimization and economic analysis on the solar PV/wind-hydrogen-PEMFC with renewable energy systems for electric supply at Gageodo island using HOMER software. The simulation results shows that cost of energy (COE) of the solar PV/wind-hydrogen-PEMFC with renewable energy is $0.957/kWh. The total net present cost (NPC) is $13.1M. The optimized size is 750 kW solar PV, 400 kW wind turbine, 2,000 kWh battery, 450 kW PEMWE, 1,000 kg hydrogen tank and 400 kW PEMFC. The excess electricity in the proposed system is found to be 58,987 kWh/year with 1.48% (13,092 kWh/year) unmet electrical load. So this optimized system can meet the load demand of Gageodo island for all seasons.

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