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COMPARATIVE ANALYSIS OF ENERGY STORAGE MODES FOR DIFFERENT RENEWABLE ENERGY SYSTEMS: A CASE STUDY ON LIUGONG ISLAND

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ABSTRACT

Carbon dioxide is one major component of greenhouse gases and is mainly caused by fossil fuels combustion.Renewable energy provides a great substitution for traditional fossil fuels because of its environmental friendness and high abundance. The deployment and application of renewable energy resources is, therefore, of great significance for improving the decarbonization and availability of island's power system. In order to address the problems caused by fluctuation features of renewable energy power generation, the utilization of energy storage measures has been increasingly proposed in recent years. This article takes the Liugong island, which is located in the Yellow Sea, as a study case and constructs an off-grid hybrid renewable energy system for this 3.15 km^2 islands. Hybrid Optimization of Multiple Energy Resources (HOMER) model based on multi-objective optimization is applied to conduct the technology-economic-environmental analysis of proposed renewable energy systems equipped with different energy storage modes. Major simulation results demonstrate that the cost of energy, the net present cost, and the reduction rate of carbon dioxide emissions for two alternative systems are 0.191 $/kWh, 7.0 million, 89.9% and 0.293 $/kWh 10.8 million, 47.6%, respectively. According to the simulation results, hybrid renewable systems with battery storage methods perform higher feasibility at current stage.

Keywords: Renewable energy; off-grid; energy storage modes; carbon dioxide emissions

1. INTRODUCTION

One main cause of global warming is the large-scale emissions of greenhouse gases, in which dioxide contributes the most. As the burning of fossil fuels produces large amounts of carbon dioxide, renewable energy has become an alternative to traditional fossil energy because of its abundance and low carbon emission. However, electricity generated by renewable resources shows the feature of fluctuation, which will lead to a substantial increase in the cost of the power system. Against this, the application of energy storage technology is particularly important. Previous studies of renewable energy systems and the energy storage technologies lay a good foundation for this study. Ye et al used Homer software to simulate an isolated island's electrical system with different energy storage methods in the south sea, China, and the simulation results indicated that the hybrid renewable energy system with hydrogen storage system with flywheel significantly reduces the excess electricity comparing to other energy storage methods.[1] Besides, Ye et al introduced a desalination system as a deferrable load based on a hybrid renewable energy system, it can not only reduce the waste of excess electricity, but also solves the problem of freshwater supply on the islands.[2] What’s more, electric cars are often parked for long periods of time, consequently, their batteries can be considered as an energy storage system, Francis Mwasilu et al reviewed the integration of renewable energy resources with electric vehicles, and the results demonstrated that electric vehicles could be deployed to cushion electric fluctuations from these batteries in the V2G mode.[3] As different energy storage modes have their respective characteristics, this paper

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attempts to carry out an integrated economy-technology-environment analysis of the Liugong island to determine the optimal energy storage mode.

2. METHODOLOGY

2.1 The basic model of this study

This paper attempts to carry out technology-economy-environment analysis on hybrid renewable energy systems equipped with different energy storage modes, with an aim to obtain the best energy storage mode suitable for the studied area. The energy storage technologies involved in this paper mainly included conventional battery storage system and hydrogen storage system. The basic idea is that the electricity generated by renewable energy power generation equipment firstly meets the island's daily electricity demand and the remainder is stored by energy storage equipment.

2.2 Homer simulation

In order to comprehensively quantify the impacts of economy, technology and environment on renewable energy system with different energy storage methods, HOMER software based on multi-objective optimization algorithm is applied. In Homer software, four input parameters are primary load, components, resources and system settings. Through the simulation process, the optimal configuration and corresponding environmental and economic results will be given.

3. CASE STUDY

Liugong island in Weihai City, Shandong province of China, is selected to be the case study area, with an area of 3.15 km^2. Liugong island has a beautiful landscape known as the sea fairy island. Hence, more and more people come here to visit the beautiful scenery, which leading to electric demand pressure to this small island. Figure.1 shows the location of Liugong island. Figure.1 comes from the HOMER software.

3.1 Available renewable energy resources

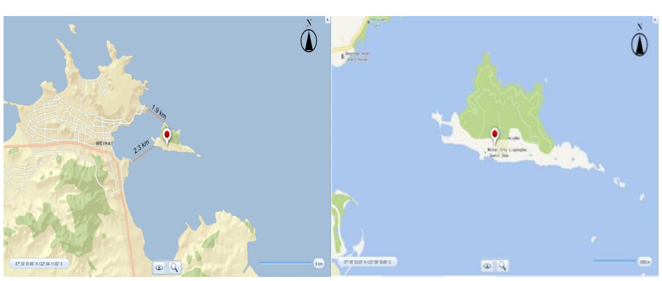

Fig 1 Location of Liugong Island

The case study island is selected to be Liugong island, located in the Yellow Sea at 37° 30′ N, 122° 10′ E. Meteorological data are used to evaluate the potential of renewable energy resources of the study area. The main renewable energy sources are solar and wind. Fig. 2 demonstrates that the range of monthly average wind speed is 5.02-8.24 m/s. Wind speed in December is highest in the year and the annual average wind speed is 6.71m/s. Fig. 3 shows the detailed data about solar radiation and clearness index, which are used to assess the solar potential of the Liugong island ' s area. As is shown in Fig. 3, the annual average daily solar radiation and clearness index are 3.86 kWh/m2/day and 0.473, respectively. The highest daily solar radiation appears in May, June and August, which means that there is great solar electric generation potential in these months. And the meteorological data comes from the NASA Surface meteorology and the Solar Energy database.

Fig 2 Wind speed of Liugong Island

Fig 3 Solar resources of Liugong Island

3.2 Estimation of power demand

In Liugong island, electricity demand is primary comes from three aspect, including household, hotel and scenic area electricity consumption. According to the local statistics in the household demand estimation, there are 200 permanent residents on Liugong island. Assuming that there are 4 members in a family, and there would be 50 families in Liugong island. Assuming that a household's daily electricity demand is 30 kWh which consist of the lighting, cooking, heating/cooling and so on, and the Liugong island's total household

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electricity consumption is 1500 kWh/day. For the hotel electricity estimation, there is only one hotel on Liugong island named Liugong Island Hotel which have 101 rooms. Assuming that a room's daily electricity consumption is 35 kWh which consist of air conditioning, lighting, TV and water heater, so the Liugong island's total hotel electricity consumption is 3535 kWh. For the scenic area's daily electricity estimation, there are 12 famous scenic spots. Assuming that a scenic spots' daily electricity consumption is 220 kWh, thus the Liugong island's total scenic electricity consumption is 2640 kWh. Apart from the above estimation, there is a health post which provide medical service during 8:00:18:00, assuming that an hour's electricity is 11kWh, so this health post's daily electricity consumption is 110kWh. Based on the above analysis, the Liugong island's daily electricity demand is 7785kWh, and the day-to-day and hour-to-hour variability are 2.92% and 7.07%, respectively.

3.3 Scenario simulation

This study constructs two scenarios by the above components, they are PV-Wind-Diesel-Battery system and PV-Wind-Diesel-Hydrogen system. According to the references[1], the capital cost of components, replacement costs, operation and maintenance costs, life cycle can be determined. Table.1 and Fig. 3 shows the detailed information about the component and configuration, respectively. The red line in the right picture of the Fig. 4 represents thermal load, the effect of the thermal load is out of consideration in this study.

4. OPTIMIZATION AND DISCUSSIONS

For the PV-Wind-Diesel-Battery scenario, the optimization results demonstrate that 1237kW generic wind turbine, 958 kW PV panels, 524kW converter ,530kW diesel generator and 429 kW battery are the best configuration, the cost of the energy is 0.191 $/kWh, the net present cost is 7 million, and the

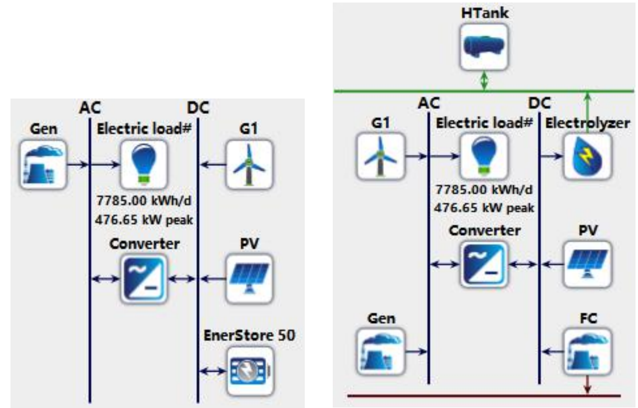

Fig 4 Different scenarios analysed in HOMER

carbon dioxide emissions are 203467kg/y. For the PV-Wind-Diesel-Hydrogen scenario, the optimization results demonstrate that 1237kW generic wind turbine, 530 kW diesel generator, 526 kW converter, 250 kW fuel cell generator, 300 kW electrolyzer and 100 kg hydrogen tank are the best configuration, the cost of the energy is 0.293 $/kWh, the net present cost is 10.8 million, and the carbon dioxide emission is 1051442 kg/y. Assuming that the electricity are only produced by diesel generator rather than any renewable resources, the cost of energy and the carbon dioxide emissions will be 0.341 $/kWh and 2004693 kg/y, respectively. The above simulation results show that the cost of energy in both cases are all lower than 0.341 $/kWh, and the rate of carbon dioxide emissions are 89.9% in PV-Wind-Diesel-Battery system and 47.6% in PV-Wind-Diesel-Battery system. Thus, the above hybrid renewable energy systems have feasibility to a certain extent.

The monthly electricity generated by different hybrid renewable power generation system are shown in Fig. 5 and Fig. 6. The PV-Wind-Diesel-Battery system produces 3708210 kWh of electricity per year, the renewable fraction and the percentage of excess electricity are 90.1 and 9.1, respectively. In the other hybrid renewable energy system, 4564138 kWh of electricity per year are generated by the system, the percentage

Table 1. Parameters of the components for this study.

Equipment	Capital cost	Replacement cost	O&M cost	Lifetime
PV	2100 $/kW	1800 $/kW	3 $/year/kW	20 year
Wind turbine	1800 $/kW	1700 $/kW	2 $/year/kW	20 year
Diesel generator	500 $/kW	405 $/kW	1 $/year/kW	25 year
Converter	300 $/kW	300 $/kW	0 $/year/kW	15 year
Battery	550 $/kW	400 $/kW	15 $/year/kW	10 year
Electrolyser	600 $/kW	500 $/kW	15 $/year/kW	10 year
Fuel cell	550 $/kW	400 $/kW	15 $/year/kW	60000 hour
Hydrogen tank	470 $/kg	400 $/kg	20 $/year/kg	20 year

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of power generation by renewable resources is 48.8, and 847140 kWh of electricity per year are not to be used, which accounts for 18.6% of the power generation by the system. Obviously, the PV-Wind-Diesel-Battery system has higher renewable energy penetration as well as lower excess electricity than the other hybrid renewable energy system. The major reason is that when hydrogen production technology is adopted to conserve excess electricity, wind power generation shows a greater advantage than photovoltaic power generation. Therefore, photovoltaic power generation is not adopted in the simulation results of hydrogen energy storage system. Besides, the wind speed in winter is higher than other seasons, thus, the major portion of electricity generated by wind turbine is in winter in both cases.

Although the cost of both energy and carbon dioxide emissions are lower than other hybrid renewable energy systems, the PV-Wind-Diesel-Battery system consumes a large amount of batteries, which not only increases the cost of the entire system, but also makes it more difficult to dispose of discarded batteries at the end of their life cycle. In addition, with the development of hydrogen production technology and the emergence of hydrogen energy vehicles, the feasibility about the PV-Wind-Diesel-Hydrogen system will increase.

5. CONCLUSION

This paper attempts to conduct a technology-economy-environment analysis of hybrid renewable energy systems equipped with different energy storage modes to determine the best hybrid renewable energy system suitable in the scope of the Liugong island. To determine the feasibility of different renewable energy systems in Liugong island, HOMER software is applied in this study. The optimization results are 1237kW generic wind turbine, 958 kW PV panels, 524kW converter, 530kW diesel generator, 429 kW battery and 1237kW generic wind turbine, 530 kW diesel generator, 526 kW converter, 250 kW fuel cell generator, 300 kW electrolyzer, 100 kg hydrogen tank in PV-Wind-Diesel-

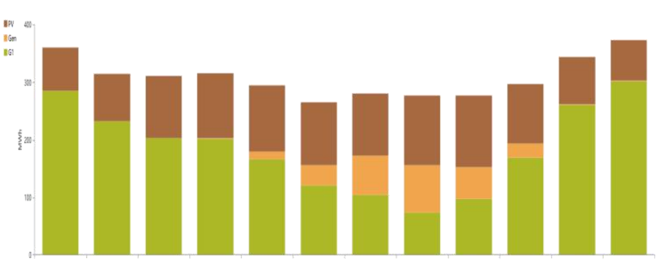

Fig 5 Monthly electric production for system with battery

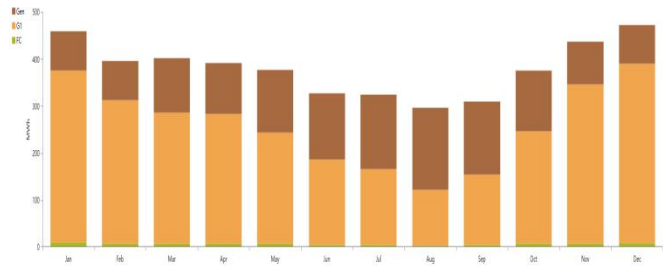

Fig 6 Monthly electric production for system with hydrogen

Battery system and PV-Wind-Diesel-Hydrogen system, respectively. The cost of energy in the hybrid renewable system with battery storage method is 0.191 $/kWh, and it can reduce 89.9% of carbon dioxide emissions compared with the cases that electricity are generated by diesel generator. In contrast, the hybrid renewable system with hydrogen storage methods' cost of energy is 0.293 $/kWh, and the 47.6% of carbon dioxide emissions reduction can be achieved in this way. According to the simulation results, the hybrid renewable system with battery storage methods has more feasibility at current stage. However, with the development of hydrogen production technology and the emergence of hydrogen energy vehicles, the hybrid renewable system with hydrogen storage methods will be increasingly feasible.

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