Renewable Energy Structure Optimization of King Island Off-grid System

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***Abstract*—With the continuous growth of global energy demand and increasing pressure to reduce carbon emissions, the transition to renewable energy and sustainable energy systems has become a crucial issue. This paper studies the energy system of King Island, Australia. The system currently consists of wind power, diesel power and limited photovoltaic power, facing challenges such as power supply reliability, renewable energy volatility and dependence on diesel backup power. Homer Pro software is used to analyze the existing system and construct different scenarios to explore potential optimization paths. Specifically, two strategies are considered: expanding photovoltaic power generation capacity and connecting more wind turbines to the grid. The modeling framework uses indicators such as renewable energy share and levelized cost of energy (LCOE) to evaluate system performance under different configurations. The study results indicate that, in the case of this island, wind power expansion is superior to photovoltaic expansion in both increasing the proportion of renewable energy and reducing power generation costs. This research provides a structured method for system configuration analysis and supports further research on optimization strategies for islanded microgrids.**

***Keywords*—renewable energy, off-grid system, King Island**

I. Introduction

In recent years, the continuous growth in global energy demand, together with the urgent need to reduce carbon emissions, has accelerated the transition towards renewable energy and sustainable energy systems. In this context, island energy systems have attracted significant attention due to their unique characteristics, including remote geographical location, limited grid connection, and a high dependence on imported fuels [1]. These factors make the integration of renewable energy both necessary and challenging.

King Island, located in Tasmania, Australia, is a typical example of an island microgrid with a relatively high penetration of renewable energy. At present, the energy system of King Island is mainly based on wind power, supported by diesel generators, while the contribution of photovoltaic (PV) generation remains limited. Although the integration of renewable energy has reduced fuel consumption and emissions, the system still faces several challenges. First, the variability and intermittency of renewable energy can affect the reliability of the power supply. Second, the continued reliance on diesel generation increases both operational costs and environmental impacts. In addition, under local resource conditions, the effectiveness of different renewable energy expansion strategies remains uncertain [2].

To solve these issues, this study uses HOMER Pro software to optimize the energy system of King Island. Based on the analysis of the current system configuration, potential development pathways are explored. Specifically, the share of renewable energy is increased by expanding photovoltaic capacity and adding more wind turbines, and the impacts of these changes on the energy structure are evaluated. In this process, the renewable energy fraction and the levelized cost of energy (LCOE) are used to assess system performance under different configurations [3]. This study aims to provide a structured analysis for the optimization of island microgrid energy systems and to support future research on renewable energy integration in similar regions.

II. Current Energy System of King Island

King Island is located in the Bass Strait between mainland Australia and Tasmania and is influenced by a maritime climate. Wind speeds are relatively high and stable throughout the year, with wind resources being particularly abundant in winter [4]. In contrast, solar energy exhibits clear daily and seasonal variations. The overall solar resource is limited throughout the year, and it is especially scarce in winter, leading to a significant reduction in solar power generation during this period [5]. It operates as an independent microgrid and is not connected to the national grid. The island's electricity supply is managed by Hydro Tasmania through the King Island Renewable Energy Integration Project (KIREIP). Before the adoption of renewable energy technologies, the island's electricity was entirely supplied by diesel generators, with a total installed capacity of 6 MW, an annual electricity consumption of approximately 12 GWh, and a peak load of about 2.5 MW. With the development of the KIREIP project, the system has evolved into a hybrid renewable energy system with high penetration, capable of meeting around 65% of the island's electricity demand using renewable sources. Under favorable environmental conditions, the system can operate on 100% renewable energy for extended periods [6].

The current energy system integrates wind power, solar photovoltaic (PV), diesel generation, and advanced energy storage technologies into a coordinated hybrid system. Wind power is the main renewable energy source, with a total installed capacity of approximately 2.45 MW. The wind farm consists of five turbines constructed in two stages, including three turbines with a combined capacity of 750 kW and two turbines with a combined capacity of 1,700 kW. Solar power generation is relatively small in scale, with a total installed capacity of about 470 kW, mainly providing supplementary electricity during the daytime. Diesel generators remain an essential component of the system, with a total installed capacity of 6 MW, providing backup power when renewable generation is insufficient to ensure system reliability. Meanwhile, energy storage plays a critical role in maintaining system stability. The system includes a battery storage unit with a rated capacity of 3 MW / 1.5 MWh for short-term energy balancing. In addition, two flywheel systems rated at 1 MVA each are installed to enhance frequency control and improve system security. To further support system operation, a 1.5 MW dynamic resistor is used to manage excess renewable energy generation, and demand-side management strategies are implemented to improve operational flexibility [6].

III. Methodology

A. System and Assumptions

This study uses HOMER Pro to model the energy system of King Island. HOMER Pro is a widely used simulation and optimization software for hybrid microgrid systems. It can simulate the interaction between different generation technologies, energy storage components, and load demand under given resource conditions, thereby evaluating different system configurations [7].

Based on the available system data, the annual electricity consumption of King Island is set to approximately 12 GWh, with a peak load of about 2.5 MW. Existing components, including diesel generation, wind power, photovoltaic (PV) generation, and energy storage, are incorporated into the model to reflect actual operating conditions. On this basis, additional renewable energy capacity is introduced to optimize the energy structure.

B. Allocation of Energy Components

1) Diesel generators

The total installed capacity of diesel generators is 4100 kW, serving as the main backup power source of the system. It is assumed that diesel generators operate only when renewable energy generation is insufficient to meet the load demand, thereby ensuring system reliability.

2) Wind turbines

Wind power generation includes two types of wind turbines. The system consists of two wind turbines with a rated capacity of 850 kW each and three wind turbines with a rated capacity of 275 kW each, giving a total installed capacity of 2525 kW. In the design, wind capacity is treated as a variable parameter, allowing additional turbines to be added to evaluate the impact of increased wind energy on system performance.

3) Photovoltaic (PV)

The initial installed capacity of the PV system is set at 500 kW, representing typical solar deployment on the island. The tilt angle is assumed to be fixed at approximately 30°. In the design, PV capacity is also treated as an adjustable variable to analyze its contribution to renewable energy within the system.

4) Battery storage

The energy storage system is modeled using 1 kWh lead-acid battery units, with a total of 2500 units, resulting in a total storage capacity of 2500 kWh (2.5 MWh). The storage system is mainly used to smooth the variability of renewable energy and improve system stability.

C. New Energy System Design

This study proposes two main scenarios to increase the share of renewable energy on King Island: increasing wind power capacity and increasing PV capacity.

In the first scenario, the capacities of other energy components remain unchanged, and only the wind power capacity is increased. Specifically, the number of 850 kW wind turbines is gradually increased from the original two units to ten units. The corresponding data are then input into HOMER Pro for analysis.

In the second scenario, the capacities of other energy components remain unchanged, and only the PV capacity is increased. Considering that there are large flat areas on the island suitable for installing solar panels, the PV capacity is gradually increased from 500 kW to 10,000 kW. Similarly, the data are input into HOMER Pro for analysis.

IV. Analysis

A. Scenario 1: Impact of Increasing PV Capacity

Under the condition that wind power capacity remains unchanged, the impact of increasing photovoltaic (PV) capacity on system performance is first analyzed. The results are shown in Fig. 1. It can be observed that, as PV capacity increases, the renewable energy fraction (Ren Frac) gradually rises, while the levelized cost of energy (LCOE) also shows an increasing trend.

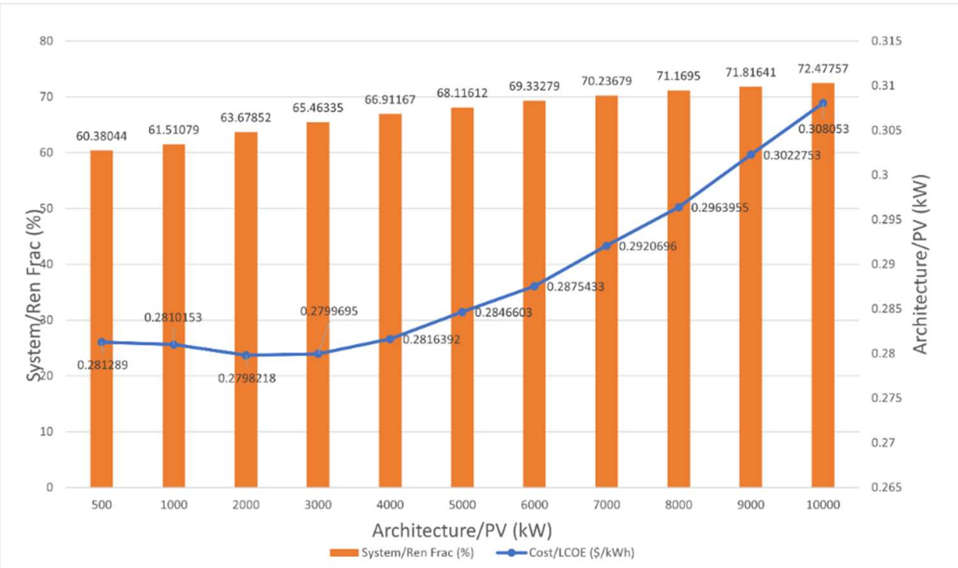

Fig. 1. The impact of PV changes on the proportion of renewable energy fraction and the levelized cost of energy.

When the PV capacity is 500 kW, the renewable energy fraction is approximately 60.38%, and the LCOE is about 0.2813 $/kWh. As the PV capacity increases to 3000 kW, the renewable energy fraction rises to 65.46%, while the LCOE remains relatively stable at around 0.2800 $/kWh. However, as PV capacity continues to increase, the marginal benefits gradually decrease. At a PV capacity of 7000 kW, the renewable energy fraction increases to 70.24%, while the LCOE rises to 0.2921 $/kWh. When the PV capacity reaches 10000 kW, the renewable energy fraction only slightly increases to 72.48%, whereas the LCOE increases significantly to 0.3081 $/kWh.

These results indicate that although increasing PV capacity can improve the renewable energy fraction of the system, its economic performance declines at higher installed capacities, with increasing unit costs and diminishing returns.

B. Scenario 2: Impact of Increasing Wind Capacity

With the PV capacity fixed at 500 kW, the impact of increasing wind power capacity on system performance is analyzed. The results, as shown in Fig. 2, indicate that compared with PV expansion, wind power expansion provides more significant improvements in system performance.

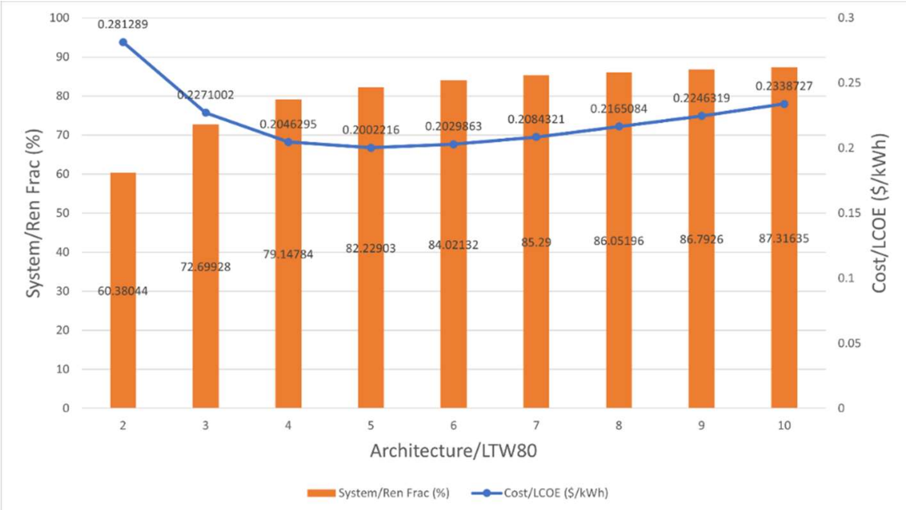

Fig. 2. The impact of wind changes on the proportion of renewable energy fraction and the levelized cost of energy.

As the number of wind turbines with a rated power of 850 kW increases, the renewable energy fraction of the system rises significantly. For example, when the system includes 5 units of 850 kW wind turbines, the renewable energy fraction reaches approximately 82.23%, while the LCOE decreases to 0.2002 $/kWh. When the number of turbines increases to 6 and 7 units, the renewable energy fraction further increases to 84.02% and 85.29%, respectively. Although the LCOE shows a slight increase with further additions (approximately 0.2030 $/kWh and 0.2084 $/kWh, respectively), it remains at a relatively low level overall.

Even at higher wind power capacities, such as a configuration with 10 turbines, the renewable energy fraction can reach 87.32%, while the LCOE remains at 0.2339 $/kWh, which is significantly lower than that in the PV expansion scenario.

These results indicate that wind power expansion not only significantly increases the renewable energy fraction, but also performs better than PV expansion in terms of economic efficiency.

C. Comparative Analysis of PV and Wind Power Expansion

A comparison of the two expansion scenarios (Figs. 3-4) shows that the differences in performance are significant.

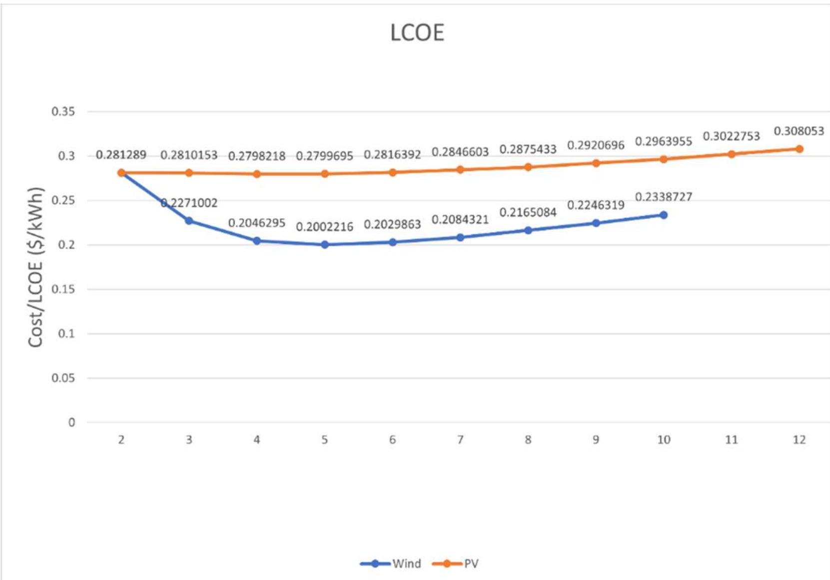

Fig. 3. Comparison of the impact of the two Scenqario on LCOE.

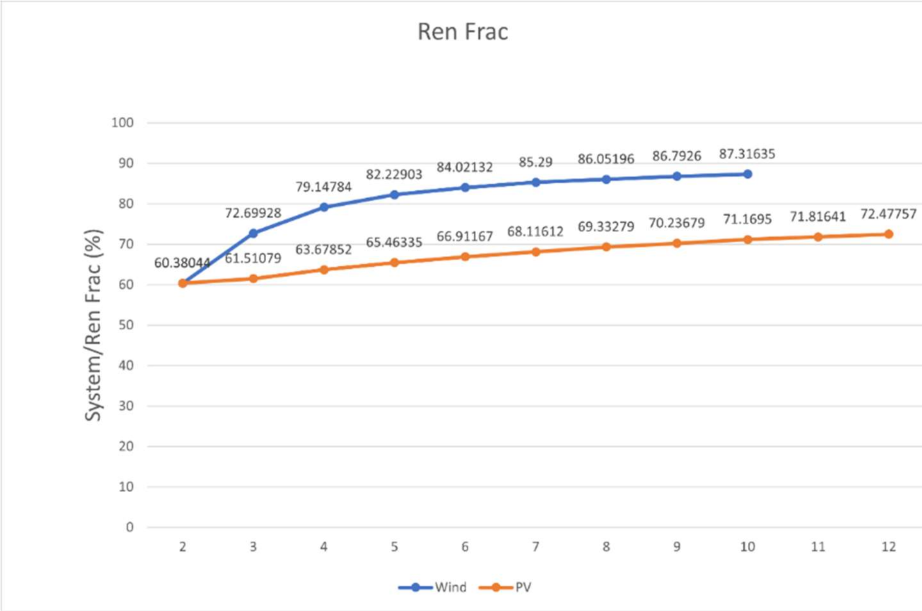

Fig. 4. Comparison of the impact of the two scenario on renewable energy fraction.

In the case of large-scale PV expansion (e.g., 10000 kW), the renewable energy fraction reaches approximately 72.48%, but the LCOE is relatively high at 0.3081 $/kWh. In contrast, under the wind power expansion scenario, a configuration with only 5 units of 850 kW wind turbines can achieve a renewable energy fraction of 82.23%, while the LCOE is only 0.2002 $/kWh.

These results indicate that wind power expansion not only achieves a higher level of renewable energy penetration, but also demonstrates better economic performance. This advantage is mainly due to the relatively strong and stable wind resources on King Island, which allow wind power to provide continuous and reliable output, especially during periods when solar energy resources are limited. Therefore, for the island microgrid system of King Island, prioritizing the development of wind energy resources is a more effective approach to improving both technical performance and economic efficiency.

V. Results

The results show that, in terms of increasing the share of renewable energy and reducing the cost of electricity generation, wind power expansion performs better than photovoltaic expansion. The possible reasons are as follows.

First, the island has relatively limited sunlight throughout the year, with a significant reduction in solar radiation during winter. As PV capacity increases, surplus electricity is likely to occur during periods of high solar radiation and low load demand. If this excess energy cannot be effectively stored or utilized, it will lead to energy curtailment, thereby reducing system efficiency and limiting the ability to provide a stable power supply throughout the year. In contrast, wind speeds are relatively stable throughout the year, and wind resources are abundant, resulting in a more stable energy supply without large fluctuations.

Second, PV generation is highly intermittent and relies more heavily on energy storage systems [8], leading to higher costs. When storage capacity is limited, further increases in PV capacity cannot be effectively converted into usable energy, thereby reducing overall system performance.

Therefore, in island microgrid systems, renewable energy development pathways should be selected based on local resource conditions. For regions such as King Island, where wind resources are abundant, prioritizing wind power development, supported by an appropriate level of PV and energy storage, is a more effective energy structure. In this study, when other components are kept unchanged, and the number of 850 kW wind turbines is increased to five units, the system achieves the lowest cost of electricity at 0.200 $/kWh, while also maintaining a high renewable energy fraction of 82.23%. This conclusion provides a useful reference for energy system planning in other islands or remote regions

VI. Conclusion

Overall, the results indicate that the choice of renewable energy type has a significant impact on both the technical performance and economic efficiency of the King Island energy system.

PV expansion can increase the renewable energy fraction from approximately 60.38% to 72.48%. However, at the same time, the levelized cost of energy (LCOE) rises from about 0.2813 $/kWh to 0.3081 $/kWh, indicating a reduction in economic performance at higher installed capacities. In contrast, wind power expansion can increase the renewable energy fraction to over 82%, reaching up to approximately 87.32%, while maintaining a relatively low LCOE (about 0.2002–0.2339 $/kWh), demonstrating better overall performance.

These results suggest that, under the resource conditions of King Island, wind power not only more effectively improves renewable energy penetration, but also has clear advantages in terms of economic performance. For the island, prioritizing wind power development, combined with an appropriate level of PV and energy storage systems, is an effective approach to improving both the technical performance and economic efficiency of the island microgrid system.

However, this study has several limitations. The analysis focuses on univariate variations, evaluating photovoltaic and wind power expansion separately rather than jointly, which may not reflect the overall optimal configuration of the system. Furthermore, due to limited hourly data, this experiment employed a simplified load distribution, and the renewable energy resource inputs were based on general estimates. These assumptions may introduce uncertainties and affect the accuracy of the results.

Future work could improve this study by conducting a multi-variable optimization in which wind and PV capacities are adjusted simultaneously to identify the most suitable energy mix for the King Island system. In addition, more detailed hourly load data and higher-resolution renewable resource data should be incorporated to improve model accuracy. A more advanced storage model that includes battery degradation, and lifetime effects could also be adopted, allowing a more realistic evaluation of long-term system performance.

Conflict of Interest

The author declares no conflict of interest.

References

[1] J. R. Kotzebue and M. Weissenbacher, "The EU's Clean Energy strategy for islands: A policy perspective on Malta's spatial governance in energy transition," *Energy Policy*, vol. 139, 111361, 2020.

[2] Hydro Tasmania, "King Island Huxley Hill Solar Farm Development Application," *Hydro Tasmania*, 2022.

[3] J. Aldersey-Williams and T. Rubert, "Levelised cost of energy–A theoretical justification and critical assessment," *Energy Policy*, vol. 124, pp. 169–179, 2019.

[4] Bureau of Meteorology, "Average Wind Speed Maps," Australian Government. [Online]. Available: https://www.bom.gov.au/climate/maps/averages/wind-velocity/, Accessed: 2025.

[5] Bureau of Meteorology, "Average Daily Solar Exposure Maps," Australian Government. [Online]. Available: https://www.bom.gov.au/climate/maps/averages/solar- exposure/, Accessed: 2025.

[6] Hydro Tasmania, "King Island Renewable Energy Integration Project (KIREIP)," Hydro Tasmania, n.d.

[7] S. W. Chisale, S. Eliya, and J. Taulo, "Optimization and design of hybrid power system using HOMER pro and integrated CRITIC-PROMETHEE II approaches," *Green Technologies and Sustainability*, vol. 1, no. 1, 100005, 2023.

[8] P. D. Lund *et al.*, "Review of energy system flexibility measures to enable high levels of variable renewable electricity," *Renewable and Sustainable Energy Reviews*, vol. 45, pp. 785–807, 2015.