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A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island

Tao Ma *, Hongxing Yang, Lin Lu

Renewable Energy Research Group (RERG), Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong

HIGHLIGHTS

- A feasibility study of a hybrid solar–wind–battery system is carried out.
- Techno-economic evaluation is conducted for this proposed system.
- Thousands of cases are simulated to achieve an optimal system configuration.
- The performance of the proposed system is analyzed in detail.
- A sensitivity analysis on its load and renewable energy resource is performed.

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ABSTRACT

This paper presents a detailed feasibility study and techno-economic evaluation of a standalone hybrid solar–wind system with battery energy storage for a remote island. The solar radiation and wind data on this island in 2009 was recorded for this study. The HOMER software was employed to do the simulations and perform the techno-economic evaluation. Thousands of cases have been carried out to achieve an optimal autonomous system configuration, in terms of system net present cost (NPC) and cost of energy (COE). A detailed analysis, description and expected performance of the proposed system were presented. Moreover, the effects of the PV panel sizing, wind turbine sizing and battery bank capacity on the system's reliability and economic performance were examined. Finally, a sensitivity analysis on its load consumption and renewable energy resource was performed to evaluate the robustness of economic analysis and identify which variable has the greatest impact on the results. The results demonstrate the techno-economic feasibility of implementing the solar–wind–battery system to supply power to this island.

1. Introduction

Energy is an essential requirement for all social activities, production of all goods and the provision of all services [1]. On the other hand, energy is also and still to be the biggest crisis to human beings, since currently the majority of the energy used on earth comes from conventional fossil fuels, and some of them will be exhausted in several decades according to the recent exploring and consuming rate. Moreover, there are still about 1.5 billion inhabitants worldwide still having no access to electricity [2,3]. The energy supply for those remote islands and villages is commonly powered by diesel generators. However, they felt more and more stressed since they often face exaggerated fuel costs due to significant rise in diesel price and extra costs of shipment. Additionally, the negative environmental effects from the employment of diesel damage the local ecological system and cause noise, water, soil and air pollution [4]. In the issue, they suffer from energy shortage or blackouts frequently.

Fortunately, remote areas are usually rich of locally available renewable energy resources. Due to the rising cost of diesel fuel and the rapidly declining cost of renewable energy technologies, the energy supply by renewables is now becoming competitive with conventional energy, thus encouraging widely utilization of renewable energy systems (RESs) for off-grid power supply, such as PV–battery, wind–battery, PV or wind based pumped storage, or hybrid systems [5–11]. Up to now, research on RESs is usually carried out in the field of system modeling, simulation, component sizing, economic analysis, and particularly system optimization [12–17]. To carry out such research, the simulation models and computer tools are generally required. Totally 37 computer tools for analyzing the RESs has been reviewed in [18], and a review of

* Corresponding author. Tel.: +852 2766 5863; fax: +852 2765 7198.
E-mail address: tao.ma@connect.polyu.hk (T. Ma).

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methodology of optimizing the hybrid RES was carried out in [19]. Among the simulation tools, HOMER (Hybrid Optimization Model for Electric Renewable) software is one of the most widely used for standalone RESs [12]. This software can assist in the design of micropower systems and facilitate the comparison of power generation technologies across a wide range of applications [20]. Using HOMER for RES modeling, simulation and techno-economic analysis has been the subject matter of substantial earlier studies, for example, the possibility of achieving energy autonomy in an island using PV, wind turbine, battery and biogas generator was examined in [21]; the pre-feasibility study of a stand-alone power generation using hybrid renewable energy with hydrogen energy storage was conducted in [22], a small Hydro/PV/Wind hybrid system in Ethiopia was examined in [23], and the economic performance of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions was analyzed in [24].

The present study is based on a research project on power supply for a small remote island in Hong Kong. The operation performance of the 19.8 kW p PV system in Stage 1 has been evaluated by the research group [25]. In Stage 2 of the island redevelopment, the wind turbine will be introduced and system capacity will increase to improve the living and facilities conditions for residents on the island. The paper focuses on investigating the feasibility of utilizing solar and wind energy to meet the electricity requirements of this remote island in conjunction with the battery storage. Specially, some basic research works in this study are reported, including feasibility study, system design, and techno-economic evaluation. The solar radiation, wind speed and ambient temperature data in 2009 has been recorded on that island for this study, and then renewable energy resource and the merit of hybrid solar and wind system have been evaluated. HOMER software is employed as a platform for sizing and optimizing the proposed system. To achieve an optimal autonomous system configuration for this island, thousands of cases in hourly basis are carried out and compared with regards to system net present cost (NPC) and cost of energy (COE). Emphasis has also been placed on analyzing the expected performance of the proposed system in detail. Moreover, the effects of the PV, wind turbine, battery bank capacity on the system's reliability and economic performance were examined. Finally, sensitivity analysis on load and renewable energy resource is performed to evaluate the robustness of economic analysis and identify which variable has the greatest impact on the results.

2. System description

There are ongoing attempts to accomplish the hybrid solar and wind system employing a battery bank. The hybrid solar–wind power generation systems can effectively improve the system energy usage factor, advance energy supply reliability, and reduce the energy storage requirements, due to complementary nature of solar energy and wind energy supply. Substantial research [9,14,26–29] has been conducted on this area, demonstrating that the hybrid system with energy storage is techno-economically viable for rural electrification in remote areas.

2.1. System configuration

The system architecture and energy flow for the proposed hybrid solar–wind system with battery storage is shown in Fig. 1. The system mainly consists of PV array, wind turbine (WT), battery bank, inverter (aka converter), controller, and other accessory devices and distribution cables. The DC power output from the PV array and WT is converted into AC by the inverter to directly supply the base load, while available excess energy is fed into the battery bank. When the battery bank is fully charged, the surplus energy is dumped if there is no more energy demand. The battery bank releases power to the load when the renewable energy output is unavailable or is insufficient to supply the load. The main power distribution component is the inverter, to which the AC and DC buses are connected. The PV array, WT and batteries supply the DC bus, and the AC bus carries power to the load side (assuming that all loads utilize AC).

2.2. System control

The system can be easily controlled because there is only one dispatchable power source, i.e. the battery bank. Whenever the net load, i.e. the difference between the actual load and the renewable energy output, is negative, meaning that power supplied by

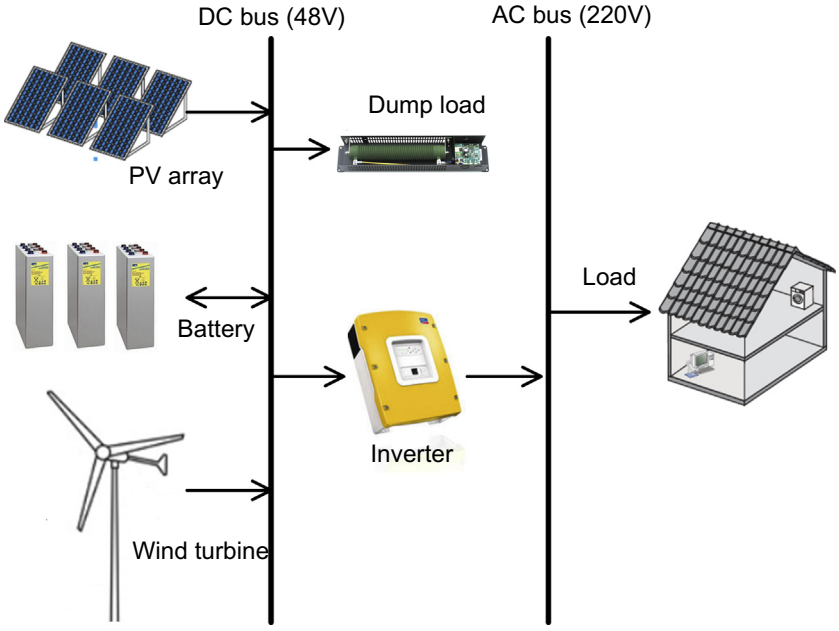

Fig. 1. The energy flow diagram of the proposed hybrid solar–wind system with battery storage.