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Study on stand-alone power supply options for an isolated community

Tao Ma *, Hongxing Yang, Lin Lu

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

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ABSTRACT

There are three inhabited islands in Hong Kong beyond the reach of the utility grid. Currently they are powered by diesel generators with fuel supplied by barge. To reduce dependence on diesel and improve power supply quality, the government is planning to explore locally available renewable energy for power generation on the islands. In this study, several power supply options such as renewable energy and diesel power generation were considered for one remotely located community. A techno-economic analysis and a detailed hourly simulation were performed to find an optimal autonomous system configuration. The results were evaluated in terms of power supply quality, life cycle cost, payback time, and greenhouse gas emission. The effects of load variation on system configuration and cost were also examined. The feasibility study demonstrates that the hybrid solar–wind–diesel–battery system could provide the optimal techno-economic performance, and this scenario was discussed with elaborate analysis. The study also shows that the energy dispatch strategy is very important for a system consisting of two dispatchable sources. Compared to a fully renewable energy system, the introduction of a back-up diesel generator in the hybrid energy system can be a more viable option, even though high diesel fuel cost is needed.

Introduction and background of this research

Up to now nearly 1.3 billion people have no access to electricity [1]. The International Energy Agency projected in 2012 that, in the absence of new actions, there will still be one billion people lacking access to electricity in 2030 [2]. Most of those people live in remote villages or islands, far away from utility grid. It is usually impractical or uneconomical to extend utility grid to those dispersed populated areas due to the prohibitive costs of constructing the network [3–5]. Therefore, electrification of those communities is covered by standalone diesel generators [6].

However, problems from diesel based power supply, such as pollution and high fuel cost, have attracted extensive public consideration of locally available renewable energy (RE) resources to supply power [7]. Advances in RE technologies and rise in cost of diesel make the RE systems becoming increasingly popular, notably in remote areas [8]. At the same time, some inter-related initiatives are also carried out to promote the RE utilization not only by the government but also the power supply companies. Recent studies [9–11] suggest that a stand-alone RE system can provide a cost-effective alternative to the expensive grid extension or diesel electrification.

In addition, renewable and nonrenewable energy sources have remarkably different economic characteristics. The high initial capital cost possibly is still the biggest barrier to RE promotion, while conventional power such as diesel tends to have high operating cost. Therefore, a trade-off between renewable energy and conventional energy should be carefully considered with respect to the lifecycle cost, environmental conservation and technical feasibility.

The Renewable Energy Research Group at the Hong Kong Polytechnic University, in collaboration with a local power supply company, is undergoing a renewable energy power supply scheme for remote inhabited islands in Hong Kong. Before the RE scheme, different supply solutions such as submarine cables and overhead lines were considered. The final decision was to take RE because it would be the lowest cost option and renewable energy technology is now mature enough to provide utility quality power supply. A series of work, such as meteorological data collection, local solar and wind energy evaluation, feasibility study, and power supply options, has been carried out for this project.

Substantial studies, such as [12–17], have been carried out on feasibility study from the point of technical or economic view on a special standalone power supply system or case studies for remote areas. However, limited study was conducted on proposing various possible power supply solutions and comparing them in detail, to achieve a feasible option and optimal system configuration. This study focuses on examining power supply options for one of the

* Corresponding author.
E-mail address: tao.ma@connect.polyu.hk (T. Ma).

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three remote islands (Town Island, Po Toi Island, and Tung Ping Chau Island) in Hong Kong. The involved island locates in the southeast of Hong Kong, currently with about 100 residents. It was formerly powered by three diesel generators of China Light & Power (CLP) [13,18,19]. However, the residents always suffered from blackouts due to high cost of diesel power generation and discontinuous diesel supply from mainland. Therefore, CLP determined to utilize RE to power this island. This research was under the request of CLP to provide references and guidance for the RE development on this island. Several options were introduced for power generation including both RE and diesel. Specifically, a techno-economic analysis and thousands of hourly simulations were performed to achieve an optimal autonomous system configuration in each option. Finally, the results of hybrid solar–wind–diesel–battery were evaluated with an elaborate analysis in terms of power supply quality, life cycle cost, and greenhouse gas emission.

Power generation system for remote areas

Before this study carried out, an evaluation of the local renewable energy resources was performed. The solar and wind energy are very good and they exhibit complementary daily and seasonal patterns, therefore these two REs are considered as the dominant renewable energy sources. The biomass is not considered as limited resource on this island. For the energy storage system, the pumped hydro storage is considered for this island, and its feasibility has been examined in other papers of the authors [13,19,20], but this technology is not utilized in the current paper, and the traditional battery storage is taken as the alternative. The motivation of this study is try to examine all possible power supply solutions for this island, including renewable and non-renewable power generation. Therefore eight possible power generation options in total are investigated, including hybrid RE and diesel system with storage and without storage.

The role of the diesel in renewable energy system

A system combining only RE and storage device is technically feasible. Technical barriers, however, will arise when the system capacity is larger than 200 kW due to the fluctuating nature of RE. Therefore, a diesel generator is included to make a hybrid RE and diesel system. The diesel generator provision can ramp up and down, to accommodate the intermittent output of RE. One advantage for including a diesel generator is the significant decrease in storage capacity of the battery bank, the PV capacity and wind turbine (WT) capacity, hence reducing system cost and improving power supply reliability, whilst an optimal combination of PV, WT and batteries can limit the fuel consumption of the generator. The studies [10,21] have demonstrated that it is more cost-effective to employ a diesel than to increase the size of the battery bank or WT or PV array for power supply to a remote area.

System configuration

The schematic diagram of a hybrid solar–wind–diesel–battery system, as an example, is presented in Fig. 1. In this system, solar and wind resources typically provide bulk energy, whereas diesel generator is performed as backup. The PV and WT produce DC power, which is converted into AC power by the converter to serve the load, and the remaining power will be used to charge the battery bank. When the RE output cannot meet the load demand, the dispatchable components (battery and diesel generator) will be launched. The converter is bidirectional, not only converting the DC power from RE and batteries to AC power for serving the load but also converting the diesel surplus AC power to charge the battery.

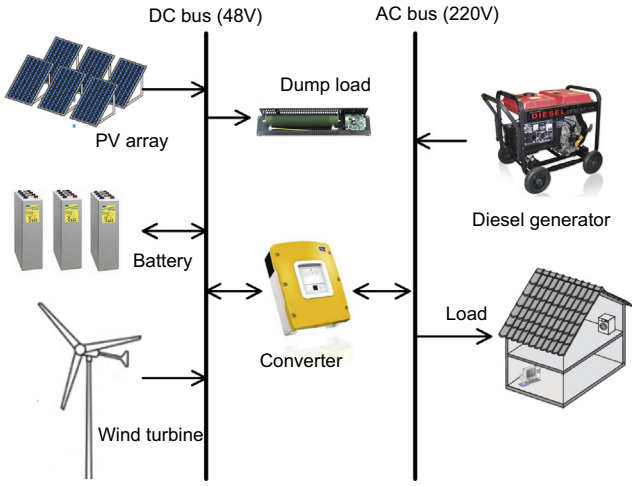

Fig. 1. System diagram of a hybrid solar–wind–diesel–battery system.

System control of dispatchable system components

The control strategy is of vital importance for hybrid systems with more than one dispatchable component. The control strategy of the hybrid RE and diesel system with battery storage, as an example, is illustrated in Fig. 2 to demonstrate the operating strategies for the system with two dispatchable power sources, i.e. diesel generator and battery bank. The control logic of dispatchable power sources is also shown in the above diagram. The operating strategy is related to the net load, the difference between the actual load and the renewable energy output, Whenever the net load is negative, meaning that the renewables are sufficient to serve the load, the excess power will charge the battery bank

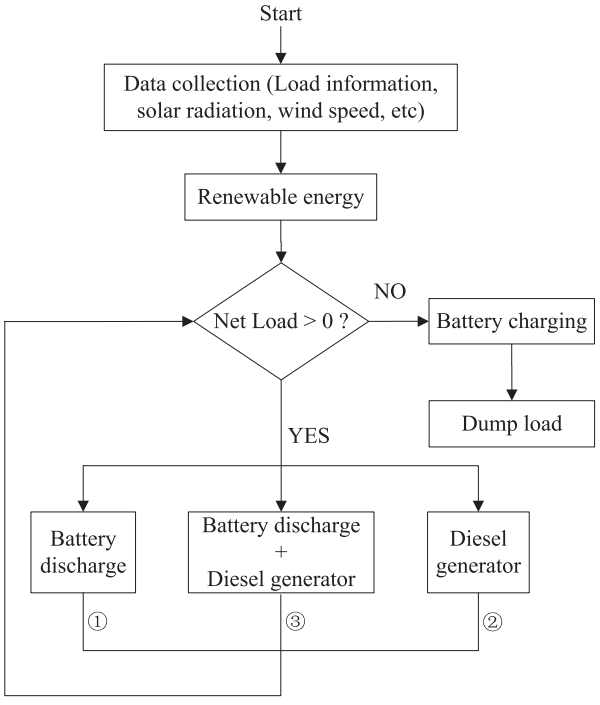

Fig. 2. Control of dispatchable system components.