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A review of renewable energy utilization in islands

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ABSTRACT

With the surge in the fossil fuel prices and increasing environmental concerns, significant efforts have been made to propel and develop alternative energy technologies to cope with the energy shortage for island power grids. Recent advancements and developments on power electronic technologies have enabled the renewable energy sources to be grid-connected with gradually higher penetration in island electricity supply. Consequently, the utilization and efficiency of renewable energy resources in islands has received remarkable attention from both the academia and industry. In this paper, a brief overview on the current status of island energy resources is described. Then, the existing utilization status and development potential of various renewable generations for island power grids, including solar, wind, hydropower, biomass, ocean and geothermal energy, are investigated. Furthermore, the advanced technologies to improve the penetration level of island renewables, including energy storage techniques, hybrid renewable energy system, microgrid, demand side management, distributed generation and smart grid, are presented.

Contents

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1. Introduction

There are more than 50 thousand islands on the earth with a total area of over one sixth of global land area [1]. More than 740 million people inhabited in islands according to geographic information system (GIS) analysis [2]. Electricity supply is an important issue in islands, and the most island power systems mainly rely on the imported fossil fuels [3,4]. However, the oil price in islands is 3–4 times higher than that in the mainland [5,6], and the island economy may be vulnerable due to oil price fluctuations. Some researches indicate that the gross domestic products (GDP) of Pacific Islands will be reduced by 1.5% due to ten-dollar hike for one barrel [7]. In recent years, the demand of energy continues to increase in islands, at an annual growth rate of 1.7% in Caribbean islands from 1970 to 2009 [8]. The oil price, with an annual growth rate of 5% over the past two decades, would grow at an annual average rate of 3% in the next 20 years [9]. Consequently, some measures should be taken to deal with energy shortage and reduce the dependence on imported fossil fuels in islands.

Greenhouse gas (GHG) emission causes global warming. CO_2 is the primary contributor of GHG, and fossil fuel combustion accounts for 90% of the CO_2 emission [10,11]. Islands are the biggest victims of global warming, especially for these low elevation islands and coastal zones. According to the Intergovernmental Panel on Climate Change (IPCC) estimates, sea level has risen eight inches since 1870 [12]. Eleven islands including Maldives, Solomon Island and Tuvalu, are facing the crisis of being submerged [13]. Meanwhile, global warming causes the destruction of ecosystems and frequent extreme weather in islands, including hurricanes, storms, floods and other cases [14,15]. Therefore, the utilization of renewable energy is of great significance for island power grids.

Although islands are faced with severe energy security, renewable energy resources, such as wind, solar, hydropower and biomass, are abundant to explore opportunities for power conversion [7,16]. Normally, each island is blessed with more than one renewable energy source for electricity utilization. Also, 100% of electricity consumption from renewable energy has even been achieved in some islands [17]. The European Island Union has established island demonstration projects to prove that energy supply in islands could rely on indigenous renewable energy sources [18].

With the recent rapid development of sustainable energy technologies and increasing demand for low-emission generation, the utilization of renewable energy shows promising prospects for island power grids. From the technical and economic aspects, it is quite feasible to substitute fossil fuels with renewable energy for island power supply [17]. At the same time, microgrid technologies provide a flexible integrated platform for the development of renewable energy, in which distributed energy could be grid-connected with high penetration. Based on the electricity demand, topographic position and renewable energy distribution, it is suitable for islands to implement microgrid [9,19]. Meanwhile, with further development of smart grid technologies including communication, monitoring, control, and self-healing, the island energy utilization to accommodate multiplying renewable energy resources has been improved [20]. Hence, the ongoing development of power electronic technologies will further propel the utilization of renewable energy in islands.

The objective of this paper is to give a comprehensive review of renewable energy utilization in islands. First, a brief overview on the current status of island energy supply systems is presented. Then, the development status and potential of renewable energy including solar, wind, hydropower, biomass, geothermal and ocean energy are summarized. Third, the approaches to enhance the penetration of renewable energy in islands are provided, including energy storage, hybrid renewable energy system, microgrid, demand side management, distributed generation and smart grid. Lastly, the conclusion is drawn.

2. Present situation of energy supply in islands

In islands, due to the isolation, small area and remoteness, the traditional energy resources are limited. For the majority of islands in the world, the imported fuel is still the main energy sources of the power supply [21]. For instance, in Caribbean islands, 90% of the energy demand relies on imported fossil fuels. In addition, fuel imports bills occupy up to 20% of annual import costs in majority of Small Island Developing States (SIDS) [22]. Some islands spend more than 30% of GDP on fuel imports. Thus, the energy cost is a great burden for islands. So far, 130 million people worldwide, one fifth of the world's population, have no access to electricity [23], and a large number of islands, particularly the small and medium-size islands, are typical areas with low electricity coverage. For instance, 70% of households in the Pacific Islands have yet no electricity, with 96% of rural residents in Solomon Island depending on traditional fuels for lighting [24].

There is usually no grid connection between islands and mainland, and even between adjacent islands due to high costs of submarine transmission cables. Therefore, the island power supply is not stable and reliable, especially under the frequent extreme weather conditions. Furthermore, most rural areas in the islands are not always covered by power supply networks. Consequently, the distributed diesel generators are often utilized for a few hours at night. Once the fuels are in short supply, the power supply will be affected and even interrupted.

Owing to the deteriorative situation of energy security and shortage, people inhabited in islands have been seeking for new energy substitutes. Thus, utilization of renewable energy has been put on the agenda [7]. Every year SIDS will convene meetings to draw up plans and share experiences [25]. Besides, the International Renewable Energy Agency (IRENA) has established Global Renewable Energy Island Network (GREIN) to provide a platform of exchange and cooperation for islands' renewable energy development. More than 60 European islands signed the “Pact of Islands” to achieve European Union (EU) sustainability targets for the year 2020 [26]. Moreover, Samsoe in the Baltic Sea, Canary Island in the North Atlantic, Reunion in the Indian Ocean, Hawaiian Island in the Pacific and Guadeloupe Island in the Caribbean islands have made use of renewable energy to a large extent.

So far, the dominated renewable energy resources used in islands are biomass energy, hydropower, wind and solar energy, and electricity generation is the main form of renewable energy utilization. Table 1 shows the current renewable energy utilization status in the selected islands across the world. It can be found that the proportion of renewable generations in the total electricity generation varies from 0% to 100% in different islands, which is 59.3% in Fiji, and lower than 10% in most of islands, even close to zero [21]. In Pellworm, a representative developed island, the electricity consumption per capita is 20,457 kWh and renewable energy generation accounts for 65.93% of the total electricity generation [17]. This is much higher than the world average level of 22.1% in 2013 [31]. Crete is a representative island devoted to the development of renewable energy. However, there is almost no renewable energy utilization in most of islands except for traditional biomass energy, such as Tuvalu in the undeveloped islands. Up to now, most islands over the world have released the development targets of renewable energy.