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Three representative island microgrids in the East China Sea: Key technologies and experiences

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ABSTRACT

In recent years, providing green and reliable energy supply to islands has appeared in the strategic plans of many countries. This paper introduces three representative island microgrids that have been built and are operating in the East China Sea. Key technologies of the island microgrids are discussed, including the analysis of island resources and load, selection of energy storage, control strategies, and energy management systems. Through analyzing their operation data for one year, this paper demonstrates the impacts of the three microgrids from the perspectives of technology, economics, and sustainability. Summarizing the experiences and insights gained from their construction and operation, this paper provides references for the future development of island microgrid projects.

1. Introduction

China has thousands of islands within its territorial waters, and sixty percent of them spread over the East China Sea. Particularly, about three thousand islands are located along the coastline of Zhejiang Province. Many of these are large islands or archipelagos, including the well-known Zhoushan Archipelago, Yuhuan Island, Dongtou Island, and Dongji Archipelago.

Large- to medium-sized inhabited islands or archipelagos usually have a large electricity demand, and thus, require highly reliable power supply due to large populations. Therefore, these locations are usually connected with inter-connected electrical networks via submarine cables. For example, the electrical network of Zhoushan district is connected to the main electrical network of Zhejiang Province through two 220 kV AC lines and three 110 kV AC lines. In addition, Zhoushan itself has a thermal power plant with a capacity of 56 MW. To further enhance the capacity and reliability of power supply to Zhoushan district, the first 200 kV DC five-terminal VSC-HVDC transmission project in the world was developed in 2014 [1]. This project has made it possible to flexibly coordinate the power generation and distribution among islands in the northern area of Zhoushan to meet the spatially distributed demand.

However, both reliability and power quality are still severe problems faced by small- to median-sized, insular islands. These islands, such as Dongji Island and Nanji Island, ranging from a few hundred square meters to about ten square kilometers, have only hundreds to thousands of island residents. They have either no connection to continental electrical networks or very unreliable connections, due to geographical obstruction, huge economic cost, and low load density. Diesel engines (DEs) have been the main method of supplying power to these islands. The expensive transporting diesel fuels to these farther detached islands, as well as the low efficiency of DEs, have tremendously restricted the economic development of these islands and the life quality of residents on the islands. More importantly, the heavy use of DEs is making the fragile ecological environment become more vulnerable to changes and may cause irreversible environmental damages. Geographically isolated small islands usually have abundant renewable energy sources (RESs) such as wind and solar energy. A potential solution to the energy shortage or high energy cost in these islands is to increase the use of renewable energy to promote a sustainable development [2]. The development of microgrid technology provides effective solutions to these problems. High penetration of renewable energy in small islands can be accomplished using energy storage systems (ESSs), advanced control strategies, and optimal energy management, with all of them being facilitated and integrated by smart grid techniques [3].

Particularly, building microgrids of renewable energy with DEs as a supplement on small islands can turn them into low-carbon or zero-

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emission islands. Needs have been identified in attempts to integrate massive wind and solar energy to existing energy systems of small islands. These include the long-term data on energy sources and loads, penetration analysis of renewable energy for such islands, methods for determining the capacity of DEs in the microgrids, approaches to selecting energy storage type and capacity, and strategies for operating the microgrids. Without addressing these, the design, construction, operations, and maintenance of the microgrids on geographically isolated small islands face great challenges.

There have been several island microgrid projects in the world. In Europe, the Kythnos Island microgrid project is built on an island located in the Aegean Sea [4], which includes 10 kW of PV, a 53 kWh battery bank, and a 5 kW diesel genset. This project aims to test the centralized and decentralized control strategies for islanding. The Isle of Eigg microgrid project is built on an island located off the Scotland Coast [5], which includes 110 kW of hydro power, 24 kW of wind turbine (WT), and 32 kW of PV. A model of Eigg is created using HOMER software and assessed to ensure that it was a valid representation of the electrical network present on the island. In Finland, an adaptive protection and microgrid control system is developed and installed at Hailuoto Island [6]. In this project, 2 WTs of 300 kW and one WT of 500 kW are built, and a DE of 1.4 MW and a WT of 500 kW are planned to be built. The system is based on a centralized controller running the real-time analysis of the data received from the field intelligent electronic devices and communicating with them through IEC 61850 communications. In France, a centralized microgrid control system for effective operation of WTs and Des, coupled with a flywheel electrical storage component, is built on Saint Paul Island [7]. The designed control strategy and communication network are then tested in a closed-loop configuration with a real-time digital simulator test bed. In Russia, a model of the campus microgrid of Far Eastern Federal University located on Russky Island is developed [8], which includes a 200 kW DE, a 17 kW PV generator, a 275 kW WT, and a 200 kW flywheel energy storage. The system can operate either in parallel with the mainland energy system or can be completely isolated. Islanding of the Russky Island power system and studying the influence of the campus microgrid on system stability are considered.

In North America, the Hartley Bay microgrid is built on a remote coastal village in British Columbia, Canada [9]. The power supply of the microgrid relies mainly on three diesel generators of 1 MW each. By optimizing the diesel dispatch and introducing the demand response technology, the annual fuel costs have been reduced significantly. The Maui Island microgrid is built on the island of Hawaii [10]. A 10 MW lithium-ion-based battery energy storage system (BESS) is designed to maintain the load frequency control by dispatching regulating reserves of active power to a 91 MW test section of the Maui Island grid model with WT of 30 MW. In South America, an optimization-based decision support strategy to enhance the management of the distributed energy sources of an islanded microgrid, implemented in a real-site microgrid on Lencois' island/Brazil, is proposed [11]. There are nine strings of PV panels of 21 kW, 3 WTs of 10 kW, a DE of 42 kW, and a battery bank of 240 Vdc nom/1200Ah. The solutions provided by the optimization algorithm are compared with the current strategy, and economic and energy savings are achieved when the optimal management of the DE is performed.

In Asia, the Miyako-Jima microgrid is built on a remote island of Okinawa, Japan [12], with an objective of providing clean and reliable power to the remote island. The project comprises 4 MW of PV, 29 MW h of battery facilities, and 1.8 MW of WTs. A diesel/PV/wind hybrid microgrid on the island of Koh Jig [13], Thailand, is built to compare the environmental impacts using life cycle assessment with the electrification alternatives of grid extension and home DEs. There are 120 panel arrays of 75 kW monocrystalline PV solar panels, a 65 kW DE, and 2 WTs of 5 kW each. A wind/PV/diesel hybrid system was built in three remote islands in the Republic of Maldives [14]. The design methodology and preliminary results were simulated and presented by HOMER. In China, the Dongao microgrid is built on an island in the South China Sea [15], which comprises an ESS of 500 kW, WTs of 750 kW, and a DE of 1 MW. A hierarchical control strategy is proposed to maintain the frequency stability on multiple time scales.

Table 1
Summary of the island microgrids.

Location	PV	WT	Diesel	Battery	Flywheel	Hydro
Kythnos Island [4]	√		√	√		
Isle of Eigg [5]	√	√				√
Hailuoto island [6]		√	√			
Saint Paul Island [7]		√	√		√	
Russky Island [8]	√	√	√		√	
Hartley Bay [9]			√			
Maui Island [10]		√		√		
Lencois' Island [11]	√	√	√	√		
Miyako-Jima Island [12]	√	√		√		
Koh Jig Island [13]	√	√	√			
Maldives [14]	√	√	√			
Dongao Island [15]		√	√	√		

The different types of island microgrids are summarized in Table 1. In general, there are five types of island microgrids, including PV/WT/Diesel, PV/Diesel/Battery, WT/Diesel/Battery, WT/Diesel/Flywheel, and PV/WT/Diesel/Battery. The installed capacity of renewable energy ranges from dozens of kilowatts to a few megawatts. Based on the above island microgrids, the control strategy and design issues are mainly discussed. However, as an important metric for the design and operation of island microgrids, renewable energy penetration has not been fully addressed. The actual operation data and related discussion of island microgrids are inadequate, and cannot show the practical effects. Therefore, there are still some issues of island microgrids that need to be further studied.

Recently, three unique stand-alone microgrid projects have been built at Dongfushan Island, Nanji Island, and Beiji Island in the east China, with an aim to replace diesel with renewable energy to improve renewable energy utilization, enhance power supply reliability, and reduce power supply cost. Particularly, some of the authors of this study was responsible for the entire design, construction, operations, and maintenance of the microgrids in Dongfushan Island and Nanji Island, gaining insights into the microgrid development for islands. Therefore, we are motivated to introduce these three microgrid projects to provide a reference for the construction of future island microgrids. Specifically, we will discuss key technologies of each project, including the data analysis of island resources and loads, renewable energy penetration analysis, selection of DE capacity and energy storage, control strategies, energy management system, and operation analysis from various aspects of microgrids.

2. Overview of three island microgrids

Three stand-alone island microgrids with distinctive features have been built and are operating normally, which are located in the Dongfushan, Beiji, and Nanji islands along the Zhejiang coast, as shown in Fig. 1. The three islands are about 40–80 km apart. Particularly, Dongfushan is the farthest eastern inhabited island in China. Table 2 summarizes the facts of the three islands, as well as configurations of the microgrids, followed by a detailed introduction of these three island microgrids.

2.1. Dongfushan island microgrid

There are about 300 inhabitants who live on fishing on Dongfushan Island. The natural environment of Dongfushan attracts tourists to visit from April to October of every year. Yet this island had a shortage of electricity and water, which had deteriorated the life quality of inhabitants and impeded the development of tourism. The developed