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Implementation of a dual-microgrid system with flexible configurations and hierarchical control in China

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ABSTRACT

This work introduces a grid-connected island microgrid in China, Luxi Microgrid, with a flexible system structure and a hierarchical control framework. To solve the low reliability issue of original electricity supply on island caused by insufficient generation and transmission capacity, a novel renewable energy system with battery energy storage was proposed in this paper. Dual-microgrid structure is adopted for the new island microgrid to provide flexible and reliable electricity services, based on 24 switching processes among 8 system configurations. The test results demonstrate that the proposed system provides seamless switching and uninterrupted power supply through the use of high voltage fast transfer switch and matched mode switching strategy. Moreover, hierarchical control framework is developed for the implement of flexible and reliable control concept, which consists of three layers: the monitoring and dispatch layer, the coordination control layer and the local control layer. The operational data are also brought forth and analyzed to provide significant and useful experiences for designing and developing similar microgrids in future.

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1. Introduction

To address urgent environmental issues, renewable energy systems are largely invested in China to promote the sustainable development of energy, economy, and society. By the end of 2012, the installed capacities of wind and photovoltaic generation in China have reached 75.3 GW and 7.0 GW [1], respectively. Both centralized and distributed renewable energy systems have been focused in the world and have been paid more emphasis in China. Among all renewable energy, the development of distributed generation will prompt revolutionary change in energy production and consumption. However, grid connection is still a challenge for the renewable energy [2].

Microgrid is an effective solution for accessing of the distributed generation (DG). The power balance of distributed generation and loads is achieved by local controlling, which also increases the efficiency of renewable energy. In addition, microgrid is conducive to improve the power quality and system reliability of traditional grid [3]. Increasing attention has been given to the research of microgrids. The microgrid demonstration projects have played an active role and become an important step to push forward the related technologies.

In the past few years, several microgrid demonstration projects have been carried out in European Union countries, U.S.A, Japan and China. Among them, typical single-bus structure was adopted in Aomori and Sendai Microgrid demonstrations supported by NEDO in Japan [4,5] and Dongfushan Island Microgrid in China [6]. Furthermore, the CERTS of U.S.A proposed the structure of single bus with a single grid-connected point [7,8]. It has high flexibility and reliability by isolating important loads with interconnection switches and supplying uninterruptible power to them. With the development of related technology, microgrids tend to more complex structures such as multi-submicrogrid topology with multiple grid-connected points, to meet the diversified user demand and more stringent requirements on reliability. Nevertheless, the relevant technical problems such as seamless mode switching, choices of synchronization brake points, protection coordination, etc., still remain challenging [9–14].

In Europe, the Dutch Continuon project demonstrated black start and autonomous switching technologies between the grid-connected and stand-alone modes. The EDP demonstration project in Portugal investigated the mode switching and load-shedding strategies. A great deal of microgrid control verification work has been done on the Germany MVV demonstration project. The black start and reconnection after the islanding operation in medium-voltage microgrid have been studied in the Bornholm demonstration project in Denmark [15,16]. The coordination control and mode switching strategies are the focuses of the present microgrid research activities that are targeted to achieve (1) power flow control of the point of common coupling (PCC) and maximum utilization of distributed generation sources, (2) stable operation in stand-alone mode, (3) fast and smooth switching between grid-connected and stand-alone operation modes in emergency or intentional islanding of microgrids [17,18].

The power supply of Luxi Island was originally depending on a 35 kV submarine cable with low transmission efficiency and poor reliability. By taking advantage of the abundant wind and solar resources on the island, a grid-connected microgrid system has been developed including wind, PV and energy storage systems. The microgrid has a flexible structure with multiple PCCs and sub-mircogrids, which includes 8 operation configurations and 24 switching processes. Moreover, the corresponding coordination control method and the intelligent mode switching strategies are proposed to achieve the economic, safe and stable operation of the system. The seamless switching between the grid-connected and stand-alone modes effectively improves the power supply capacity and reliability.

The rest of this paper is organized as follows: Section 2 introduces the system configuration and the flexible dual-microgrid structure of Luxi Microgrid. Section 3 describes the hierarchical control framework in detail, including the economic dispatch, the coordination control and the mode switching strategies. The actual experimental and operational data are given in Section 4 to verify the performance of the proposed hierarchical control framework and the related control strategies. Section 5 concludes the paper.

2. System configuration and dual-microgrid structure

Located in the eastern coast of China (121.20°E, 27.98°N), Luxi Island has about 8000 local residents, who mainly live on fishing. Before the construction of the microgrid, there was only a 35 kV substation with a 10 MVA main transformer on the island which was connected to the main grid (i.e. Wenzhou Power Grid) through a 35 kV submarine cable and provided power to the whole island. In the distribution network of the island, there were 47 distribution transformers with a total capacity of 6735 kVA. 15 of those distribution transformers (with a capacity of 2965 kVA in total) were for regular customers while the rest (with a capacity of 3770 kVA in total) were for sensitive customers. Due to the frequent submarine cable damage accidents caused by the anchors of fishing boats, the original power supply system on the island suffered with low power reliability. In addition, Luxi grid was weak end of Wenzhou Power Grid. Although the total demand is much less than the capacity of main transformer, load shedding often happened during summer peak seasons due to the insufficient capacity of the main power grid.

Unreliable power supply significantly impedes the development of local economy. To address this issue, a 10 kV and MW level grid-connected microgrid system is proposed. The system is developed with high reliability and flexibility of power supply and to fulfill different electricity service needs via seamless switching between the grid-connected and the stand-alone modes [19,20].

2.1. System configuration

The peak load of Luxi Island is around 3.5 MW and the base load is almost 1.5 MW, including 0.8 MW of sensitive load. To mitigate the impact of load shedding during the summer peak season, a battery energy storage system (BESS) is adopted with the power electronic converters. The transmission capacity of tie-line between the island and the main grid is around 2 MW. So the capacity of the power electronic converters for BESS should be 1.5 MW (i.e. 3.5 MW minus 2 MW). While considering the safety margin, the rated capacity of converters is chosen as 2 MW. The peak load of Luxi grid could last about 1–1.5 h by analysis of