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An integrated energy storage system based on hydrogen storage: Process configuration and case studies with wind power

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ABSTRACT

The interconnection between a renewable power generation facility and a power grid poses challenges because of volatility and intermittent characteristics. Energy storage is one of the best solutions for this problem. This paper presents an integrated energy storage system (ESS) based on hydrogen storage, and hydrogen–oxygen combined cycle, wherein energy efficiency in the range of 49%–55% can be achieved. The proposed integrated ESS and other means of energy storage are compared. The results show that the proposed integrated system cannot be constrained by geological conditions and availability of materials, and appears to be an appropriate tool for the development of renewable power. Moreover, a case study is conducted for a special wind power plant with a nominal power of 100 MW and that generates electricity of 225 GWh/y. The integrated system is designed based on the daily wind load. Energy efficiency and preliminary economic comparison studies for the integrated system operated in two modes show that up to 50% average net efficiency of the integrated ESS can be achieved and that the integrated ESS can stabilize the intermittent wind power. Therefore, the integrated ESS can be useful to mitigate the bottleneck of renewable power development.

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1. Introduction

The revitalization of China's long-term planning of renewable energy predicts that the installed capacity of wind power in China will reach 150 million kW in 2020. Therefore, the installed capacity of wind power in proportion to the total electricity will be enhanced. The dependence on fossil and nuclear fuels and the greenhouse effect caused by fossil fuel burning will be reduced. The rapid development of wind power as a representative of renewable energy eases the pressure on the traditional power grid and improves the energy structure. Wind power not only brings environmental and economic benefits but also many uncertain challenges.

The traditional power grid has a significant influence on the current status and situation of the wind power connection to the grid [1]. For example, the stochastic volatility of wind power causes a certain impact on the power grid. Wind power capacity is limited by low voltage ride through (LVRT) and often runs off-grid when the large grid fails. Wind power, as a new distributed energy joining the network, has changed the coordination control strategy in the regional grid. Moreover, a large number of wind farms were carelessly installed because of the impact of the local government's policy direction. These wind farms increased the pressure on the grid, and the "rubbish electricity" phenomenon occurred. To resolve the series of problems caused by the rapid development of wind power, all countries have committed to pursue scientific and rational approaches to wind power joining the large grid and to create a new path toward the sustainable development of wind power. The network experience in new energy power generation in recent years has generally recognized the necessity to develop storage technology suitable for a large scale clean energy grid connecting to a power grid with stable and reliable operation. Recent domestic and international studies have focused and emphasized on new energy storage technology.

Energy storage technology is a system that equalizes electricity generation and load demand. The storage system operates to store energy during off-peak periods and runs the generator to provide stable power during on-peak periods. The energy storage system (ESS) was based on the integration of energy storage technology. ESS generally consists of two parts, energy storage devices and

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power conversion systems. A major goal of energy storage is to achieve the transformation of an energy medium for energy storage and release. A power conversion system achieves the operation of an automatic control system. ESS not only compensates for the shortcomings of intermittent and volatile wind power but also improves the controllability of wind farms, the quality of electrical energy, and the economy of the entire power grid. A study [2] proposed optimum energy storage techniques for the improvement of renewable energy sources-based electricity generation economic efficiency, and a systematic parametrical analysis concerning the effect of the ESS's main parameters on the economic behavior of the entire installation is examined in detail.

This study proposes a renewable, pollution-free, and environment friendly ESS based on the study of the current methods of energy storage technologies that employ hydrogen as an energy medium and that have sustainable development features. This study also deals with a selected "wind case" in Jiangsu Province, designs a wind-hydrogen and hydrogen–oxygen combined cycle system, analyzes the wind load curve, and models the system based on Aspen Plus.

2. Summary for ESS

Energy storage technology provides a simple solution to the balance of electricity supply and demand. In the late nineteenth century, the lead-acid battery ESS was used in the power supply system of New York City. The energy was stored during the day, and then the generator was operated at night. Battery power was used for street lighting. People have developed various storage methods. Energy storage technology has four types based on the different methods of energy conversion such as mechanical, phase change, electromagnetic, and electrochemical mechanical energy storage converts electrical energy into physical potential energy. The potential energy is the intermediate energy of physical media to store and generate the electrical energy. The two main forms of energy are potential energy and kinetic energy. Electromagnetic energy storage converts electrical energy into electromagnetic energy for storage. Superconducting magnetic energy storage (SMES) and super capacitor energy storage (SCES) are two main forms of electromagnetic energy storage. Electrochemical energy storage selects a chemical medium to store energy. Ice storage is typical phase change energy storage. Fig. 1 shows the main energy storage methods.

2.1. Common ESS

2.1.1. Compressed air energy storage (CAES)

CAES is an energy storage method that maintains balance between demand and production. CAES is based on conventional gas turbine technology [3]. A simple CAES model is shown in Fig. 2. Energy is stored by compressing air in the pipe, solid airtight facilities, or an airtight underground storage cavern. When the price of electricity is high, we can generate electricity using fully compressed air and fuel mixture. The first commercially operated CAES was a 290 MW unit built in the Huntorf plant in Germany in 1978 [4]. The second one was a 110 MW unit that operated in Alabama. The unit could get into the grid within 14 min. These units provide valuable experience for the later development of a CAES power station. To improve the energy storage density of compressed air, in the Institute of Engineering Thermophysics, Chinese Academy of Sciences Chen Haisheng conducted simulation studies to improve the workability of the quality of a compressed air unit and to reduce unit quality compressed air volume. A study [5] discussed and analyzed the use of CAES with air injection concept and supercharging with inlet chilling, the result showed that the mean values of power generated, energy ratio, and primary efficiency of CAES-IC system are about 7% higher, 3.3% lower, and 1% higher than the corresponding values with CAES-AI system. A study [6] proposed a hybrid wind–diesel system with CAES, and finally proposed a numerical model of each of its components, demonstrating the energy efficiency of the system.

2.1.2. SMES

In early 1911, the Dutch physicist discovered the superconductor in a trial process [7]. However, in the 1970s, scientists proposed that SMES, as a new type of ESS, could be applied to the modern power network. SMES became well known in ESS because of its good technical characteristics. SMES can store energy without loss in the long-term. The system can send back the energy efficiently, and its conversion efficiency is much higher than that of other storage systems by up to 95%. Domestic agencies have conducted many studies on SMES. The Institute of Electrical Engineering at the Chinese Academy of Science developed a 1 MJ/0.5 MW, high temperature superconducting energy storage. Tsinghua University, Huazhong University of Science and Technology, North China Electric Power University, and other universities also conducted research on SMES. The study [8] presented an optimized design of the SMES system to achieve a maximum energy capacity. A control system using a digital signal processor and micro-programmed control unit is constructed. Space vector pulse width modulation is used as a control strategy. The result validates the design and control circuit, and more importantly, the application capability of SMES systems in a power grid. At present, SMES, as a short-term energy storage form, is extensively used in wind power generation systems [9]. Low-temperature SMES (1 MJ/MW to 5 MJ/MW) have been produced, and 100 MJ SMES have been operated in high-voltage power grids. Another study [10] identified and evaluated

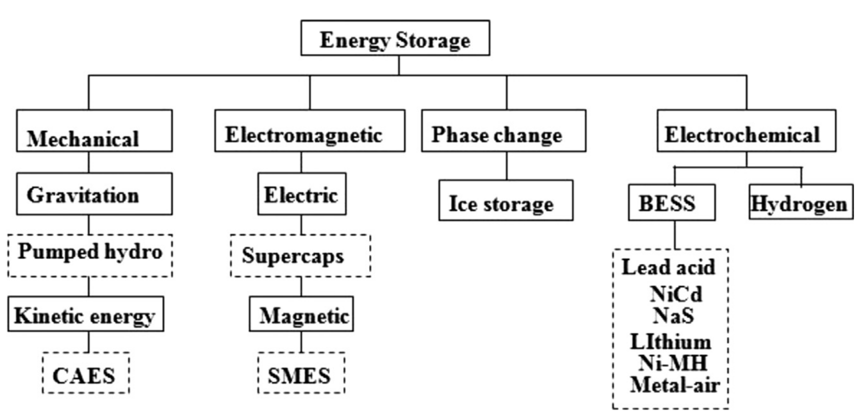

Fig. 1. Classification of the main energy storage methods.

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