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Energy storage system: Current studies on batteries and power condition system

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ABSTRACT

To maximize the introduction of renewable energy, introducing grid energy storage systems are essential. Electrochemical energy storage system, i.e., battery system, exhibits high potential for grid energy storage application. A battery energy storage system is comprised of a battery module and a power conversion module. This paper starts by reviewing several potential battery systems, as well as an advanced aluminum-ion battery that currently has promising prospects in the electrochemical energy storage system. The characteristics of the batteries are reviewed and compared, including the materials, electrochemistry, performance and costs. The application prospect of the batteries is discussed. The paper summarizes the features of current and future grid energy storage battery, lists the advantages and disadvantages of different types of batteries, and points out that the performance and capacity of large-scale battery energy storage system depend on battery and power condition system (PCS). The power conversion system determines the operational condition of the entire energy storage system. The new generation wide bandgap semiconductor for power electronic technology is discussed from the perspective of performance, topology, model and non-linearity and is compared to the traditional silicon-based semiconductor. Finally, the application prospect of the new generation semiconductor technology in the energy storage system is indicated. This paper concludes the application status of the energy storage system in the renewable energy power generation and indicates the critical problems that need to be addressed during the construction and operation of the storage system.

1. Introduction

Carbon emissions have caused 4 °C (7.2 °F) of warming that could cause a sufficient eventual sea level rise to submerge land that is currently home to 470–760 million people globally [1]. To cope with global climate changes and energy supply shortages and to achieve carbon emission reductions, developed countries must adjust development strategies in succession, formulate new low carbon-oriented patterns of economic development, and initiate strategic moves toward a low-carbon economy. As a high energy-consuming country, America mainly uses electricity (68.4%) generated from thermal power stations. According to the future energy plans announced by the U.S. Department of Energy, 20% of the electricity in America will be generated from wind power and 10% of the electricity will come from solar photovoltaic power by 2030 [2].

In Germany, the high number of installed intermittent renewable energy systems has had a significant influence on the operation of power systems and coal power plants. By 2034, the total installation capacity of wind power and solar photovoltaic power is expected to be approximately 173 GW, twice the current peak power in Germany. However, the instant power supply gap between the intermittent fluctuation of the intermittent renewable energy and the demand fluctuation of the load side was as high as 74.335 MW, which was equivalent to 92% of the peak loading in Germany. To guarantee the stability of the power supply, the German power grid operator adjusts the electricity generation schedule of the coal power plant to increase the amount of elasticity generation [3].

Due to the variable and intermittent nature of the output of renewable energy, this process may cause grid network stability problems. To smooth out the variations in the grid, electricity storage systems are needed [4,5]. The 2015 global electricity generation data are shown in Fig. 1. The operation of the traditional power grid is always in a dynamic balance status between electricity generation and electricity consumption, which is the so-called status of immediate electricity generation and immediate electricity utilization. Therefore, the planning, operation and control of the power grid is conducted based on the principle of balance between supply and demand: the generated power must be transmitted immediately, and there must be a

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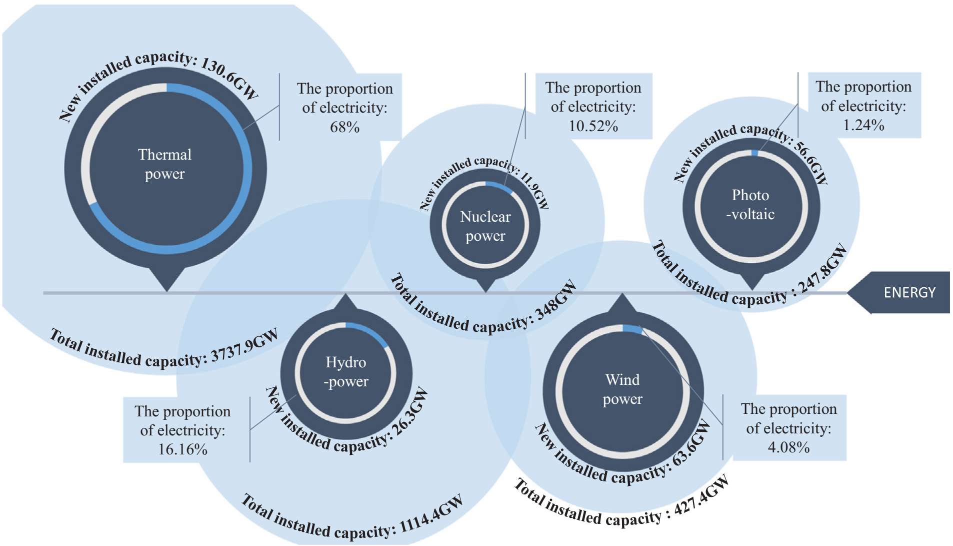

Fig. 1. 2016 Global renewable energy installed capacity.

real-time balance between power utilization and power supply. Such planning and construction thinking gradually demonstrates its defects and limitations as increasingly intermittent renewable energy systems have been installed. Therefore, the dispatching, control and management of the power grid are thus becoming increasingly difficult and complicated. The upsurge of renewable energy system installation is an important step in promoting energy saving and CO_2 emission reduction and pollution control. However, the fact is that numerous installed renewable energy systems cannot be fully loaded, leading to a massive amount of waste in the electricity generation from renewable energy systems [6].

After the installation of high-performance and large-scale energy storage technology, electricity will become a commodity, and then can be stored. This will cause fundamental changes in the concepts of power generation, transmission, distribution, and consumption, in which power system operation and management must be done. The concepts of alternative clean energy and alternative electric energy will lead renewable energy and sustainable energy to strongly permeate the new generation power grid [7]. The power electronization of power systems is the inevitable trend of its development. Power electronic technology is the core technology of electricity storage systems, which is used to solve the large-scale connection, high-capacity and long-distance transmission and the distributed micro-grid of the new energy. Additionally, as battery technology does, power electronic technology plays an important role in the energy storage system. A new generation of semiconductor technology and other power electronic technology will speed up the development of the large-scale energy storage system.

In this paper, the application of battery and power conversion technology in energy storage systems is introduced. This paper first reviews some batteries which can be potentially applied as a core component of the electricity storage system. Then, the wide bandgap semiconductor of power electronic technology based on performance, topology, model and non-linearity were reviewed and compared to the traditional silicon-based semiconductor. Additionally, the application prospect of new generation semiconductor technology in the energy storage device is discussed.

2. Application of the battery energy storage system and the large-scale energy storage project

Because the energy storage technique possesses an extremely high strategic position, all countries around the world continuously support the fundamental researches and application projects of the energy storage techniques. In 2013, Japan's New Energy and Industrial Technology Development Organization (NEDO) conducted the development of route planning aiming at all types of battery energy storage techniques, which paid special attention to the development of techniques, e.g., lithium-ion (Li-ion) batteries, sodium-sulfur batteries and advanced batteries [8]. At the end of 2014, the United States Department of Energy (US DOE) released relevant technical reports on the development and application of all types of advanced batteries, and special attention will be paid to research directions such as super lead acid and advanced lead acid batteries, Li-ion batteries, sulfonic batteries, flow batteries, metal-air batteries and advanced compressed air energy storage technology [9].

Batteries, which are an electrical energy storage technology that has high investment benefits at present, is characterized by modularization, rapid response and a high commercialization potential. With the technical innovation and successful development of the new batteries, the efficiency, power density, energy density and cycle life of batteries have improved remarkably. The battery system is associated with flexible installation and short construction cycles and therefore has been successfully applied to grid energy storage systems [10]. The operational and planned large scale battery energy systems around the world are shown in Table 1 [11].

A basic battery energy storage system consists of a battery pack, battery management system (BMS), power condition system (PCS), and energy management system (EMS), seen in Fig. 2. The battery pack has a modular design that is used in the integration, installation, and expansion. The BMS monitors the battery's parameters, estimates its current capacity, and controls the overall system. The PCS is involved in the rectification and inversion function necessary for the conversion between AC and DC electric energy. Based on the mode setting or load change, the energy management system is responsible for the effective scheduling and management of the energy storage system in meeting the seamless connection requirement between the communication and scheduling of the station's main engine [12,13].

With its high specific energy density and strict application requirements, the battery has to be restricted and protected by continuously checking the single battery cell voltage and current in the process of charge and discharge [14]. Because of the differences in the manufacturing processes and application environments, their initial differences occur in the batteries' capacities, as well as attenuation speeds [15]. To ensure the long-term operation and improve the utilization efficiency of the battery pack, balancing the electric quantity of each single battery cell is essential. For industrial demands, the need for parallel connection of the battery is huge, thus a BMS needs to be introduced to manage well the array of the battery components, ensure the consistent status of each