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Review of energy storage system for wind power integration support

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HIGHLIGHTS

- The principle and characteristics of present EES technologies are reviewed.
- The potential applications of different roles played by EES are described.
- The recent researches about the EES planning problems, including type selection, optimal sizing and siting are summarized.
- The operation and control strategies are discussed.

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ABSTRACT

With the rapid growth of wind energy development and increasing wind power penetration level, it will be a big challenge to operate the power system with high wind power penetration securely and reliably due to the inherent variability and uncertainty of wind power. With the flexible charging–discharging characteristics, Energy Storage System (ESS) is considered as an effective tool to enhance the flexibility and controllability not only of a specific wind farm, but also of the entire grid. This paper reviews the state of the art of the ESS technologies for wind power integration support from different aspects. Firstly, the modern ESS technologies and their potential applications for wind power integration support are introduced. Secondly, the planning problem in relation to the ESS application for wind power integration is reviewed, including the selection of the ESS type, and the optimal sizing and siting of the ESS. Finally, the proposed operation and control strategies of the ESS for different application purposes in relation to the wind power integration support are summarized. The conclusion is drawn in the end.

1. Introduction

Nowadays, as the most popular renewable energy source (RES), wind energy has achieved rapid development and growth. According to the estimation of International Energy Agency (IEA), the annual wind-generated electricity of the world will reach 1282 TW h by 2020, nearly 371% increase from 2009. By 2030, that figure will reach 2182 TW h almost doubling the year 2020 production [1].

Due to the intermittent nature of wind power, the wind power integration into power systems brings inherent variability and uncertainty. The impact of wind power integration on the system stability and reliability is dependent on the penetration level [2]. From the reliability perspective, at a relative low penetration level, the net-load fluctuations are comparable to existing load fluctuations [3], and the Conventional Generators (CGs), such as thermal or hydro units, have sufficient load tracking capability without requiring additional operating reserve. As the wind penetration level increases, the response time of committed CGs should be short enough during sudden and large changes of wind power production and load due to random failures and wind gusts, and more operating reserves will be required. From the stability perspective, different from synchronous generators, Wind Turbine Generators (WTGs) provide only small or even no contribution to frequency stability [4]. The wind power variation can also degrade the grid voltage stability due to the surplus or shortage of power [5]. An Energy Storage System (ESS) has the ability of flexible charging and discharging. Recent development and advances in the ESS and power electronic technologies have made the application of energy storage technologies a viable solution for modern power application [6]. The potential applications mainly cover the following aspects. Through time-shifting, the power generation can be

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regulated to match the loads. The ESS can also be used to balance the entire grid through ancillary services, load following and load leveling [7]. Moreover, it can meet the increasing requirement of reserves to manage the uncertainty of wind generation [8] which can increase the system operation efficiency, enhance power absorption, achieve fuel cost savings and reduce CO_2 emissions. Additionally, the ESS is a potential solution to smooth out the fluctuations, and improve supply continuity and power quality [9].

For a specific application, the first task of an ESS project is planning. It generally includes the type selection and size determination. Sometimes, the ESS siting also needs to be considered. Several factors, such as technical features, economical cost and local wind power characteristics, can influence the ESS selection [10]. Once a specific ESS type is chosen, the optimal sizing needs to be done by balancing the benefits and cost. If there are no geographical constraints, the ESS could be optimally installed to achieve the maximum benefit, mainly in the reduction of transmission system upgrade cost.

The operation and control strategies of the ESS are designed for different application purposes. The recent studies mainly focus on the coordinated control of wind farms and on-site ESSs. The short-term (daily or hourly) dispatch scheme of an ESS and fluctuation smoothing by a wash-out filter are the two attractive areas. It is also proposed to combine many dispersed ESSs as a virtual storage unit and control centrally [10]. Since the ESS is an expensive solution, it is not economically viable for the ESS to work for a single application service. It can also contribute to the system wide control.

This paper is to review the state of the art of the ESS technologies and the applications for the wind power integration support from different aspects. The paper is organized as follows: Section 2 introduces the principle and characteristics of present ESS technologies. The potential different roles played by the ESS for the wind power integration support are described in Section 3. The recent research of the ESS planning problem, including type selection, and optimal sizing and siting, are summarized in Section 4. Finally, the operation and control strategies of the ESS for wind power integration support are discussed in Section 5. The conclusion is drawn in Section 6.

2. Energy storage technologies

The electrical energy can be stored in different energy forms: mechanical, electro-chemical, chemical, electromagnetic, thermal, etc. [3,7]. The classification of energy storage technologies according to the stored energy form is illustrated in Fig. 1.

There are various characteristics of the ESS required to be taken into consideration for different applications, including capital cost, power and energy rating, power and energy density, ramp rate, efficiency, response time, self-discharge losses, and life and cycle time [11,12]. The overview of the capital cost and the technical features of the ESS is listed in Tables 1 and 2, respectively.

The technical details of the ESS have been described in many literatures [10,11,13,14]. A short description of the principles and potential capability of several commonly used ESSs for wind power integration support is presented in this section.

2.1. Pumped Hydro Storage (PHS)

The PHS is the largest and most mature energy storage technology available [15]. It represents nearly 99% of the worldwide installed electrical storage capacity with over 120 GW [10,16]. The conventional PHS consists of two water reservoirs. The water body at the relatively high elevation represents the potential or stored energy. During off-peak hours, it pumps water from the lower reservoir to the upper one, considered as a charging process. In the discharging process, water from the upper reservoir is released and flows through hydro turbines which are connected to generators, producing electrical energy [14].

As illustrated in Table 2, the PHS has the largest power and energy rating, long lifetime, high efficiency and very small discharge losses. The main applications of the PHS for wind power integration are energy management via time-shifting, frequency control and non-spinning reserve supply. Due to the slow response, the PHS is not suitable for suppressing wind fluctuations. The installation of the PHS is dependent on geographical conditions and has an impact on the nature environment. Therefore, the flexibility of its application is low.

The economic benefits of the PHS combined with Wind Farms (WFs) are described and analyzed in [17,18] shows that the hybrid PHS-WF system can meet the hourly energy demand.

2.2. Compressed Air Energy Storage (CAES)

The CAES is a technology known and used since the 19th century for different industrial applications [10]. Electrical compressors are used to compress air and store it in either an underground structure (salt cavern, abandon mines, rock structures) or an above-ground system of vessels or pipes. When needed, the compressed air is released and mixed with natural gas, burned and expanded in a modified gas turbine. Current research on the CAES is focused on the development of systems

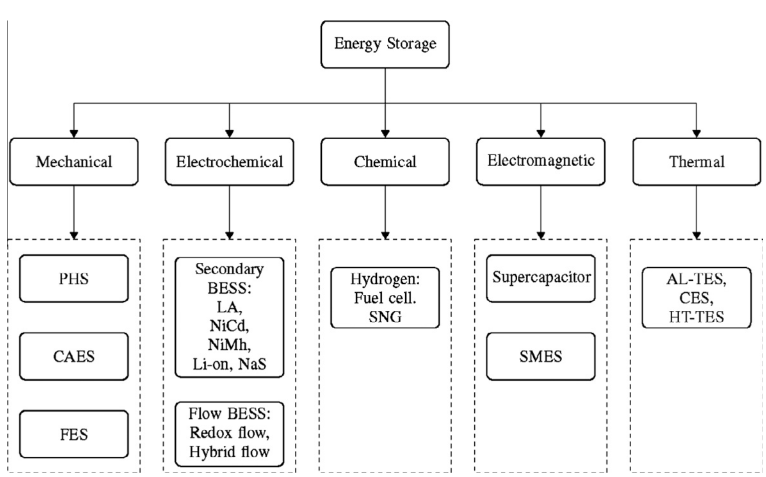

Fig. 1. Energy storage classification.