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A comparative overview of large-scale battery systems for electricity storage

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ABSTRACT

In this work, an overview of the different types of batteries used for large-scale electricity storage is carried out. In particular, the current operational large-scale battery energy storage systems around the world with their applications are identified and a comparison between the different types of batteries, as well as with other types of large-scale energy storage systems, is presented. The analysis has shown that the largest battery energy storage systems use sodium–sulfur batteries, whereas the flow batteries and especially the vanadium redox flow batteries are used for smaller battery energy storage systems. The battery electricity storage systems are mainly used as ancillary services or for supporting the large scale solar and wind integration in the existing power system, by providing grid stabilization, frequency regulation and wind and solar energy smoothing.

Contents

1. Introduction

Balancing power supply and demand is always a complex process. When large amounts of renewable energy sources (RES), such as photovoltaic (PV), wind and tidal energy, which can change abruptly with weather conditions, are integrated into the grid, this balancing process becomes even more difficult [1–3]. Effective energy storage can match total generation to total load precisely on a second by second basis. It can load-follow, adjusting to changes in wind and PV input over short or long time spans, as well as compensating for long-term changes [4]. While conventional power generation plants may take several minutes or even hours to come online and will consume fuel even on spinning reserve standby, storing renewable energy for later use effectively produces no emissions. Some well established technologies offer significant energy storage capacity but require specific geographical features

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and considerable infrastructure. Others can be deployed rapidly to whenever they are required, but currently offer restricted capacity, often at high cost [20].

Although, due to their cost, batteries traditionally have not widely been used for large scale energy storage, they are now used for energy and power applications [6]. Energy applications involve the storage system discharge over periods of hours (typically one discharge cycle per day) with correspondingly long charging periods [7]. Power applications involve comparatively short periods of discharge (seconds to minutes), short recharging periods and often require many cycles per day. Secondary batteries, such as lead–acid and lithium-ion batteries can be deployed for energy storage, but require some re-engineering for grid applications [8].

Grid stabilization, or grid support, energy storage systems currently consist of large installations of lead–acid batteries as the standard technology [9]. The primary function of grid support is to provide spinning reserve in the event of power plant or transmission line equipment failure, that is, excess capacity to provide power as other power plants are brought online, especially in the case of isolated power systems [10]. These systems can take energy from the grid when either the frequency or voltage is too high and return that energy to the grid when the frequency or voltage begins to sag [11]. The current implementation can provide a few minutes of energy, but overall grid management, including shifting peak loads, and supporting RES, will require longer durations of storage and therefore re-engineering of storage systems to handle greater energy to power ratios [12].

In this work, a comparative overview of the different types of batteries used for large-scale electricity storage is carried out. In particular, the current operational large-scale battery energy storage systems around the world with their applications are identified and a comparison between the different types of batteries, as well as with other types of large-scale energy storage systems, is presented.

In Section 2, the different types of batteries used for large scale energy storage are discussed. Section 3 concerns the current operational large scale battery energy storage systems around the world, whereas the comparison of the technical features between the different types of batteries as well as with other types of large scale energy storage systems is presented in Section 4. A comparison of economic and environmental features of the large scale energy storage systems is discussed in Section 5. Finally, the conclusions are summarized in Section 6.

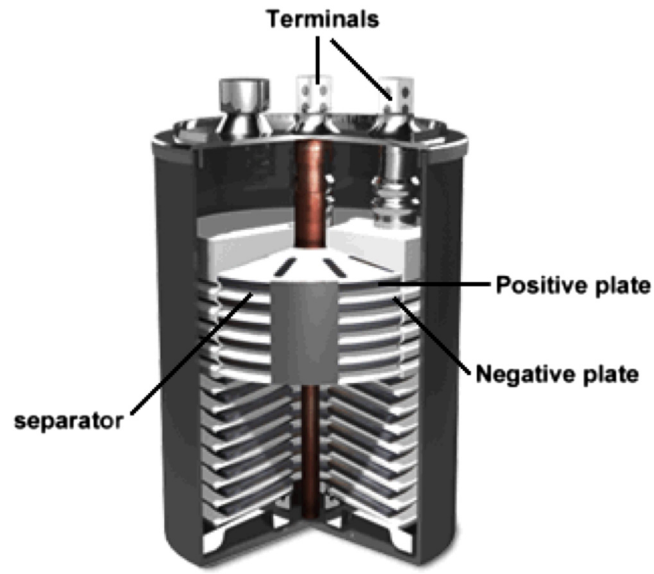

Fig. 1. Structure of lead–acid battery [88].

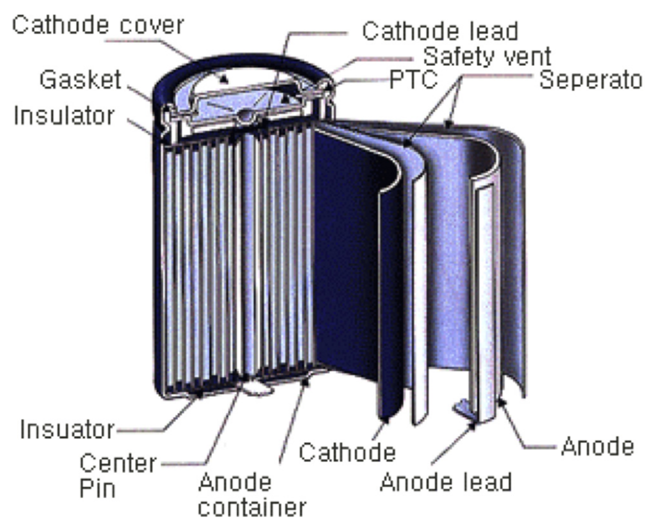

Fig. 2. Structure of lithium-ion battery [89]

2. Large scale battery energy storage systems

Several types of batteries are used for large scale energy storage [13,14]. All consist of electrochemical cells, though no single cell type is suitable for all applications [15,16]. In this section, the characteristics of the various types of batteries used for large scale energy storage, such as the lead–acid, lithium-ion, nickel–cadmium, sodium–sulfur and flow batteries, as well as their applications, are discussed.

2.1. Lead–acid batteries

Lead–acid batteries, invented in 1859, are the oldest type of rechargeable battery and they use a liquid electrolyte, as illustrated in Fig. 1. The technology of lead–acid batteries is uncomplicated and manufacturing costs are low; however, such batteries are slow to charge, cannot be fully discharged and have a limited number of charge/discharge cycles, due to their low energy-to-weight ratio and their low energy-to-volume ratio [17]. The lead and sulfuric acid used are also highly toxic and create environmental hazards, which can be particularly ironic when used to accompany clean sources of power such as PV systems [5].

The lead–acid battery chemistry can be modified for grid storage applications beyond stabilization applications by modification of the electrode structures. Lead–carbon electrodes are designed to combine high energy density of a well designed battery with the high specific power obtained via charging and discharging of the electrochemical double layer. Lead–carbon electrode research has been focused on the extension of cycle life durability and specific power [18]. Carbon is added to the negative electrodes, and while the carbon does not change the nature of the charge transfer reactions, it increases specific power and reduces the incidence of sulfation during charging cycles, which is one of the principal failure modes of traditional lead–acid batteries [19]. In these applications, it is required to have relatively deep discharges with good cycle life. With new carbon enhanced negative electrodes in valve regulated lead–acid (VRLA) batteries, the cycle life is improved up to a factor of 10 at significant rates [12].

In RES applications multiple deep-cycle lead–acid (DCLA) batteries, which provide a steady current over a long time period,