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Emergence of hybrid energy storage systems in renewable energy and transport applications – A review

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A R T I C L E I N F O

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A B S T R A C T

The idea of Hybrid Energy Storage System (HESS) lies on the fact that heterogeneous Energy Storage System (ESS) technologies have complementary characteristics in terms of power and energy density, life cycle, response rate, and so on. In other words, high power ESS devices possess fast response rate while in the contrary, high energy ESS devices possess slow response rate. Therefore, it may be beneficial to hybridize ESS technologies in the way that synergize functional advantages of two heterogeneous existing ESS technologies As a consequence, this hybridization provides excellent characteristics not offered by a single ESS unit. This new technology has been proposed and investigated by several researchers in the literature particularly in the fields of renewable energy and electrified transport sector. In this context and according to an extensive literature survey, this paper is to review the concept of the HESS, hybridization principles and proposed topologies, power electronics interface architectures, control and energy management strategies, and application arenas.

Contents

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1. Introduction

Matching renewable generation intermittency to demand in an electricity supply system was the reintroduction of the Energy Storage System (ESS) technologies in the power systems [1]. Besides storing and smoothing renewable power, there are numerous advantages related to the advent of ESSs in the power systems. ESSs can increase power system operation and planning resiliency and efficiency by means of many applications including [2–10]:

- Energy time shift
- Supply capacity
- Load following
- Area regulation
- Fast regulation
- Supply spinning reserve
- Voltage support
- Transmission congestion relief
- Transmission and Distribution upgrade deferral
- Power quality
- Renewable energy time shift
- Renewable capacity firming
- Renewable energy smoothing
- Service reliability
- Black-start

In addition, rapid growth of the electric and hybrid vehicle technology opens a new era on ESS [11–13]. However, ESS solutions are not quite commercially or technologically mature in many features causing obstacles to their extensive utilization. The ESS technologies are different in terms of cost and technical properties such as [10,14,15]:

- Energy and power rating
- Volumetric and gravimetric energy density
- Volumetric and gravimetric power density
- Discharge time
- Response time
- Operating temperature
- Self-discharge rate
- Round-trip efficiency
- Life time (years and cycles)
- Investment power and energy cost
- Spatial requirement
- Environmental impact
- Recharge time
- Memory effect (batteries)
- Maintenance requirements
- Recyclability
- Technical maturity
- Transportability
- Cumulative energy demand

Despite numerous research efforts in order to improve ESS capabilities over the past decade [1], a perfect ESS technology that copes the drawbacks in terms of all aspects is not to be expected to develop in the near future. On the other hand, particular ESS applications require a combination of energy and power rating, charge and discharge time, life cycle, and other specifications that cannot be met by a single ESS technology. In order to increase the range of advantages that a single ESS technology can offer and at the same time enhance its capabilities without fundamental development of the storage mechanism and only via complementary use of the existing ESS technologies, more than one ESS technologies can be hybridized [16]. A Hybrid Energy Storage system (HESS) is composed of two or more heterogeneous ESS technologies with matching characteristics and combines the power outputs of them in order to take advantages of each individual technology and at the same time hide their drawbacks. In this context, this paper is to review the previous literature on HESSs and extend them through presenting a review of the state of the art. The remainder of the paper is organized as follows: Section 2 introduces the hybridizing criterion and proposed schemes in the literature. The HESS architectures are described in Section 3. Control and energy management issues are discussed in Section 4. Finally, the application areas are summarized in Section 5. The conclusion is drawn in Section 6.

2. Hybridization criterion

The ESS technologies can be classified in three categories regarding type of the stored energy, including mechanical, electrical, and chemical as shown in Fig. 1. Each technology encompasses several different properties which should be taken into account in different applications. As listed in Table 1, typical properties for different technologies consist of power rating, discharge time, power density, energy density, and lifetime in both years and cycles [8,10].

As could be observed from Table 1, ESS technologies can classify into two main categories including high power and high energy technologies. High power storage systems supply energy at

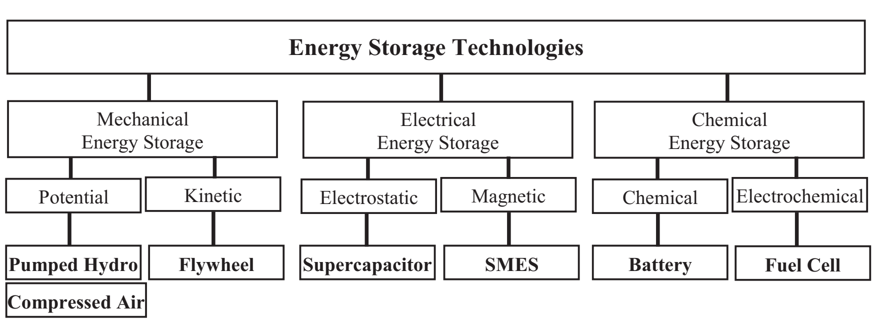

Fig. 1. ESS technologies classification.