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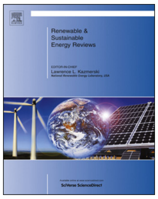

Electrical energy storage systems in electricity generation: Energy policies, innovative technologies, and regulatory regimes

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ABSTRACT

Electricity plays a dominant role to the citizens' well-being and the social prosperity of the developed economies. Electricity perspectives have attracted the research interest of the scientific community during the last two decades due to its determining impact upon transportation modes (electric-based mobility: electric vehicles–EVs, hybrid cars, and electric drive-trains), energy-consumed household tasks (Smart House and Smart Grid concepts), working environment, and leisure activities. Electricity generation is mainly determined by the following features: on-grid (mainland) and off-grid (including exploitation of renewables in remote areas) production, peak (during the day) and off-peak (during the night) daytimes of energy production and consumption, efficient and reliable power supply, capability and reliability of energy storage technologies, energy market potential in the future. This study further explores the following issues: which technologies will be most needed, in which technologies there is room for further development, which policy considerations will influence rollout and penetration, and what implementation problems may be expected. Finally, this study addresses a wide spectrum of energy policies regarding the electrochemical, mechanical, and thermal energy storage technologies. In parallel, the study discussed global regulatory regimes of the post-2015 development agenda of Rio20+ United Nations Conference on Sustainable Development that should be adapted to electricity generation under the political initiatives of “Sustainable Development Goals” (SDGs) and “Millennium Development Goals” (MDGs). Finally, the key-issues of research, operation, applicability, and pricing trend of energy storage technologies are addressed while the future orientations of these technologies are outlined.

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1. Introduction

The imperative role of electricity is defined by its socio-economic impacts, especially in Western Europe and China (due to its ongoing developmental growth forecasted). Indeed, the activities involved in the energy sector increase the employment and reinforce the social cohesion of all citizens. Besides, the activities involved in the energy sector foster the collective actions of citizens initiatives and governmental policies towards environmental sustainability, materials exploitation, issues on land use – such as degradation and desertification of soils – legislatively protected ecosystems, terrestrial carbon sequestration, climate change mitigation, and low-cost mass production techniques. These collective actions should be also taken under consideration whenever policy makers draw a strategic plan for reliable supply and efficient use of electricity. Subsequently, it is of utmost importance that robust energy storage systems should support autonomous operation, energy storage safety standards, easy extension, and coordination with grids [92]. It is noteworthy noting that what constitutes good technologies mainly depends on the perspective of the decision maker, whereas the features of efficiency and lifetime of the energy storage technologies are less important factors while implementing these technologies in small-scale or large-scale applications [95].

A typical strategic plan of an Electrical energy storage (EES) scheme should evaluate the following issues: estimation of the flexibility and feasibility of the energy marketplace towards the implementation of new EES schemes, balanced co-existence of conventional technologies with the development and diffusion of EES innovative technologies, participative role of renewable energy sources (RES) to the existing basket of energy sources utilized, as well as compatibility of EES with other existing businesses that are related to the energy marketplace [92]. In parallel, the EES perspectives are determined by the pronounced diversifications upon the value and the market size for each EES technology, as well as the future socio-economic and technological circumstances in the energy marketplace [92]. Besides, the maturity of the EES technologies in the energy marketplace should be affected by the EES opportunities and the EES constrains of each technology. EES opportunities refer to the simultaneous installation of multiple applications, based on the pace and the scale of renewable energy development. In parallel, EES constrains refer to the imperative need for sophisticated procurements of market mechanisms, balancing energy and controlling interoperability – since renewable energy generation causes fluctuations on the supply side to increase. Finally, Research and Development (R&D) on EES technologies should be focused on Western Europe and China – since a trend of high renewable energy penetration is expected at both context, where the potential development of EES technologies in these marketplaces is relatively high [92].

2. Innovative EES technologies – a literature review

In response to the electricity role in the European Union, the International Electrotechnical Commission - Market Strategy Board (IEC-MSB) established a project team in October 2010 to investigate the current situation and the future orientation upon the electrical energy storage (EES) technologies, roles, markets, and perspectives. The outcomes of this project have been collected and presented in a White Paper [92]. According to Ref. [92], Germany is a leading country for the introduction of renewable energies, thus its energy enlargement – through EES development – is expected. Particularly, the share of renewable energy contribution to the total energy production in Germany is targeted to increase from less than 20% today to around 60–80% by 2030 (3–4 times higher than present allocation in installed storage capacity). This goal should be accomplished by increasing the penetration capacity of renewable energy, mainly, though the optimum exploitation of wind (almost twice percentage contribution than solar to energy profile in Germany) and solar. On the other hand, the EES technologies of pumped hydro (PHS) and compressed air energy storage (CAES) sustain limited future potential in Germany due to the lack of suitable spacious locations or underground formations, as well as due to the high cost for their full deployment, involved [92]. The main concepts of this collective reference are outlined as follows [92]:

A power system is structured upon the connectivity of power grids with generators and consumers. Electricity production and consumption has to be always balanced, since any imbalance between supply and demand will cause power flow congestion on the power lines, instability of power supply, quality fluctuation – in terms of voltage and frequency – electrical interruption, as well as seasonal variations in the cost of electricity generation [92]. In cases of mismatch between supply and demand, shortage of supply is conventionally backed up by a reliable power supply, such as fossil-fueled generators. A geographic mismatch in an area can be decreased by reinforcement of interconnections with neighbouring areas, and time mismatch can be solved by the EES time shift function. Additionally, the maintenance of a continuous and flexible power supply for consumers, factories and commercial facilities is essential, since any imbalance between the proper amount of electricity supply at the time when consumers need it results in the fluctuation of smooth power supply and possibly the interruption of the service. In this study a literature review was conducted regarding the published studies upon the EES technologies. These studies were collected in a round period of the last decade of publication (period 2005–2015), and are presented in reserve chronological order (from newest to oldest) in following Table 1.

3. Forms and features of EES technologies

This section provides a fundamental theoretical and technical overview upon the aforementioned EES technologies reviewed. In particular, EES technologies can be classified according to energy form of the storage systems, such as: mechanical, electrochemical, chemical energy, electrical, and thermal. Key-factors of an EES technology are the physical facilities, interactions with existing uses of gas, optimal chemical processes, safety, reliability and efficiency. A compare-and-contrast evaluation among the aforementioned technologies in terms of rated power, energy content, and discharge time at each technology showed that the most advantageous and mature technologies (but also showing lower power density) are proven the PHS, Hydrogen, and Synthetic Natural Gas (SNG) storage systems, accordingly. Nevertheless, some of the EES technologies outlined in the White Paper are still in a pilot, demonstration, or projected levels of development [92]. Indeed, PHS installed capacity reaches 127 GW, that corresponds to 99% of the total installed capacity of EES systems used in electricity grids and it is about 3% of global generation capacity. The second largest EES in installed capacity is the CAES power plants, but there are only two systems in operation. Even though both PHS and CAES technologies are already economically feasible, no EES technologies have been put into practical operation with the specifications of long discharge times (up to months) and huge capacities (up to TW h). Besides, there is also room to further development of new long-term EES technologies – such as H_2 and SNG. The efficiency of full-cycle conversion of electric power to these two technologies ranges at 50–75%. An extensive overview of the technical specifications, capital costs, advantages, and