



Energy storage technologies and real life applications – A state of the art review



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HIGHLIGHTS

- Primary and secondary energy forms introduced.
- Different (electrical and thermal) energy storage technologies presented and compared.
- Real life energy storage application analysed to understand the most widely applied technology.
- Challenges facing the energy storage industry summarised.
- Future prospects of the energy storage sector predicted.

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ABSTRACT

Energy storage is nowadays recognised as a key element in modern energy supply chain. This is mainly because it can enhance grid stability, increase penetration of renewable energy resources, improve the efficiency of energy systems, conserve fossil energy resources and reduce environmental impact of energy generation. Although there are many energy storage technologies already reviewed in the literature, these technologies are currently at different levels of technological maturity with a few already proven for commercial scale application. Most of the review papers in energy storage highlight these technologies in details, however; there remains limited information on the real life application of these technologies for energy storage purpose. This review paper aims to address this gap by providing a detailed analysis of real life application and performance of the different energy storage technologies. The paper discusses the concept of energy storage, the different technologies for the storage of energy with more emphasis on the storage of secondary forms of energy (electricity and heat) as well as a detailed analysis of various energy storage projects all over the world. In the final part of this paper, some of the challenges hindering the commercial deployment of energy storage technologies are also highlighted.

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1. Introduction

Energy in whatever form is an essential commodity globally. It is the most common consumer good and has continued to be a key element to the worldwide development. Energy comes in various forms although it can be broadly classified into two [1]. They include: primary and secondary forms of energy. Primary energy are regarded as those energy sources that only involve extraction or capture, with or without separation from contiguous material, cleaning or grading, before the energy contained in it can be converted into heat or mechanical work [1]. They are usually found in nature. They include all energy forms which have not been subjected to any conversion or transformation process. Typical examples are crude oil, coal, biomass, wind, solar, tidal, natural uranium, geothermal, falling and flowing water, natural gas, etc. On the other hand, secondary forms of energy include all energy forms which occur as a result of the transformation of primary energy using energy conversion processes. Fig. 1 shows the relationship between the primary and secondary energy forms.

Secondary energy forms are more convenient forms of energy as they can directly be used by humankind. They are also known as Energy Carriers (EC). Examples of secondary energy forms are electricity, gasoline, diesel, ethanol, butanol, hydrogen, heat. Table 1 shows the different primary energy forms and the corresponding technology used to transform it to secondary energy form.

Cumulatively, energy consumption has been growing significantly over the years. According to the 2014 key world energy statistics released by the International Energy Agency (IEA), about 13,371 Mtoe of energy is supplied globally in 2012 [2]. This is about 10% and 119% higher than the 2009 and 1973 values respectively [3,4]. Although there is an increasing trend in the global energy supply, the percentage share of fossil fuel has been decreas-

ing gradually due to the penetration of renewable energy systems. For example, approximately 82% of the primary energy supply in 2012 came from fossil fuels compared to 87% in 1973 [2]. However, this reduction in fossil fuels share in the primary energy supply does not portray in actual terms a reduction in CO₂ emission. For example, fossil fuels contributed about 31,734 Mt of CO₂ emissions in 2012 compared to 16,633 Mt in 1973 [2,4].

CO₂ emissions from fossil fuels have been identified as a major global environmental threat due to its contribution to global warming. For the past years, many efforts have been made to reduce CO₂ emission in order to mitigate the associated environmental impact. These range from creating new and innovative energy conversion technologies to improving the efficiency of existing energy conversion technologies. Furthermore, reducing energy wastage from a variety of industries whether domestic or commercial by storing them for future use has a very significant impact in reducing CO₂ emission. The need to balance the mismatch between energy supplied to the grid and the energy actually used from the grid by storing the excess energy is equally important to achieving a low carbon economy. It is against this backdrop that energy storage is believed to be essential in the modern energy supply chain as it will help to plug the leakages and improve efficiency. As a result of this, energy storage has recently attracted the attention of governments, stakeholders, researchers and investors as it may be used to improve the performance of the energy supply chain.

1.1. Motivations for energy storage

Energy storage is an essential link in energy supply chain. For example, it is a fact that there is no system that is 100% thermodynamically efficient. The energy losses in most systems occur in the

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