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Review

Overview on recent developments in energy storage: Mechanical, electrochemical and hydrogen technologies

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ABSTRACT

Energy production is changing in the world because of the need to reduce greenhouse gas emissions, to reduce the dependence on carbon/fossil sources and to introduce renewable energy sources. Despite the great amount of scientific efforts, great care to energy storage systems is necessary to overcome the discontinuity in the renewable production. A wide variety of options and complex characteristic matrices make it difficult and so in this paper the authors show a clear picture of the available state-of-the-art technologies. The paper provides an overview of mechanical, electrochemical and hydrogen technologies, explaining operation principles, performing technical and economic features. Finally a schematic comparison among the potential utilizations of energy storage systems is presented.

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Nomenclature

BESs	Battery Energy Storage system
BMS	Battery Management System
CAES	Compressed Air Energy Storage
CNT	Carbon Nano Tubes
DoD	Depth of Discharge
ED	Energy Density
EE	Energetic Efficiency
ESS	Energy Storage System
FES	Flywheel Energy Storage
PaT	Pump as Turbine
PH(S)	Pumped Hydroelectric (Storage)
RFB	Redox Flow Battery
SES	Supercapacitor Energy Storage
SMES	Superconducting Magnetic Energy Storage
SoH	State of Health
T&D	Transmission and Distribution
Mtoe	Million Tonnes of Oil Equivalent

1. Introduction

"Energy" can be considered a prerequisite of the countries development and one of the most important factor to increase people wellness. For this reason the world energy diet shows a steady growth (+56% from 1990 until 2015) in the last years mainly due to the Asian continent (see scenario of Fig. 1), while North America and European Union slightly decrease energy demand from 2008 due to the economic crisis. Fortunately, in the last 20 years, energy production from renewable sources has risen continuously (see Fig. 2). The Italy scenario is a good further example of energy production due to the great amount of energy plants for renewables production. In fact, Fig. 3 shows the Italy trend of energy production in the 2005–2015 interval (data provided by national energy services manager, GSE). The slight decrease in renewables production in 2015 (vs 2014) is due to a minor rainfall in this last year.

The reasons that explained this increase of attention about renewables are the lack of carbons and the necessity to offer a best future to 4.5 billion of people who today have a limited access to energy resources, and this also matches the international environment treaties to reduce world pollution, i.e., Kyoto Protocol, EU 2020. Despite this trend, renewable sources are still unable to overcome the other energy sources for mass energy production because of their random behaviour [1–3]. For instance, the biogas production from biomass relies on the performance of a cultivation, but in a more general way, on the employed "digestion" processes [4–6]. Eolic and solar generations are characterized by the greatest availability, but are considered to be unpredictable. An additional important aspect that should be considered is that generally the load curves almost never follow the energy availability curves. Consequently, the direct consumption of energy produced from renewable sources can be very inefficient and inadequate because a large amount of energy is over-produced and then most commonly wasted, as well as, is not directly recovered in other cases (e.g., thermal conversion). This asynchronous production against energy demand can represent a limiting factor to the further development of renewables. The only solution to continue improving renewables is the energy storage. For these reasons the increase in scientific research into energy storage systems is highly desirable. The use of an Energy Storage System (ESS) can raise the energy production efficiency [7,8]. It is charged with energy surplus coming from the production phase, while when the production is insufficient or absent, the needed amount of energy is withdrawn by its discharging. Moreover, such system allows separating, both in space and time, the power production from its consumption.

In this way, it would be possible to achieve the transition from a localized energy production (few big power plants) to a grid energy production (more and smaller power plants). This change would increase the global efficiency of the whole energy production-distribution system, reducing the losses in the Transmission and Distribution (T&D) process and being much more environmental friendly due to the lower fossil fuel consumption and pollution emissions [4].

A huge variety of energy storage systems is available. Usually, it is possible to provide a classification based on the energy conversion mode. Therefore, they can be divided as follows:

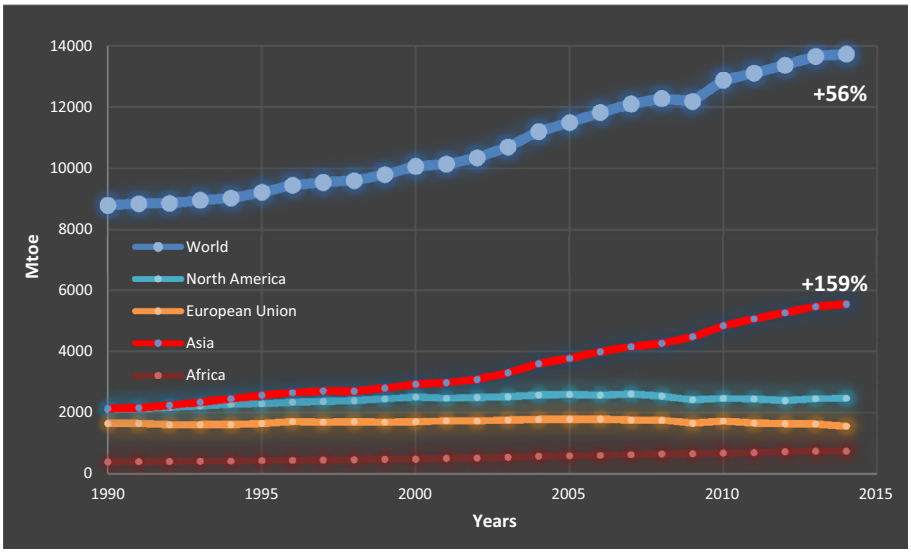

Fig. 1. World energy diet (Mtoe), adapted from ENERGY DATA - Global Energy Statistical Yearbook 2015.

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