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Review

Energy storage: Applications and challenges

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ABSTRACT

In this paper, an updated review of the state of technology and installations of several energy storage technologies were presented, and their various characteristics were analyzed. The analyses included their storage properties, current state in the industry and feasibility for future installation. The paper includes also the main characteristics of energy storage technologies suitable for renewable energy systems.

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1. Introduction

Energy continues to be a key element to the worldwide development. Due to the oil price volatility, depletion of fossil fuel resources, global warming and local pollution, geopolitical tensions and growth in energy demand, alternative energies, renewable energies and effective use of fossil fuels have become much more important than at any time in history [1,2]. Current and future markets in fossil fuels are subject to volatile price changes in oil and natural gas. National and international energy/environmental crises and conflicts are combining to motivate a dramatic paradigm shift from fossil fuels to reliable, clean and efficient fuels. Using renewable energy sources seems a promising option; however, there are still some serious concerns about some renewable energy sources and their implementation, e.g. (i) capital cost and (ii) their intermittent nature in power production [3–6]. Renewable energy resources such as wind and solar energies cannot produce power steadily, since their power production rates change with seasons, months, days, hours, etc. The cost issues depend mainly on how research and development can be successfully carried out in these areas. Extensive public and private researches and development efforts to achieve technological breakthroughs are required to bring these technologies to commercial maturity. Therefore, in order for the renewable energy resources to become completely reliable as primary sources of energy, energy storage is a crucial factor [7,8]. Essentially, energy from these renewable resources must be stored when an excess is produced and then released. There are other reasons why it is necessary to store energy [5–8]. Storing energy allows

- to meet short-term, random fluctuations in demand and so avoid the need for frequency regulation by the main plant. It can also provide 'ride through' for momentary power outages, reduce harmonic distortions, and eliminate voltage sags and surges;
- to eliminate the need for part-loaded main plant which is held in readiness to meet sudden and unpredicted demands, as well as power emergencies which arise from the failure of generating units and/or transmission lines;
- to accommodate the minute–hour peaks in the daily demand curve;
- to store the surplus electricity generated overnight (i.e. during off-peak hours) to meet increased demand during the day;
- to store the electricity generated by renewables so as to match the fluctuating supply to the changing demand.

Through such applications, it is also considered that energy storage can be multi-beneficial to both utilities and their customers in terms of (i) improved efficiency of operation of a system; (ii) reduced primary fuel use by energy conservation; (iii) provided security of energy supply; (iv) decreased environmental impact.

Energy storage in a power system can be defined as any installation or method, usually subject to independent control, with the help of which it is possible to store energy generated in the power system, keep it stored and use it in the power system when necessary [9–13]. According to this definition, energy storage may be used in the power system in three different regimes: charge, store and discharge. In each of these three regimes a balance between power and energy in the power system has to be maintained so the energy storage has to have the appropriate rated power and energy capacity. The duration of each regime, its switching time and storage efficiency are subject to power system requirements. Before installing any device in a power system, we will define the power system requirements for energy storage as a margin for its rated power and energy capacity, its efficiency, switching time and duration of its regimes. It is clear that these margins – power systems requirements – are subject to the function performed by energy storage in a power system.

Different energy storage technologies coexist because their characteristics make them attractive to different applications. In general, energy storage systems can be described as either electrical or thermal [14–19]. Electrical energy storage includes a broad range of technologies, which either directly or indirectly provide electrical energy storage via an electrical input and output. The principal technologies are

- electrochemical systems (embracing batteries and flow cells);
- kinetic energy storage systems, more commonly referred to as flywheel energy storage;
- potential energy storage in the form of either pumped hydro or compressed air storage.

In contrast, thermal energy storage systems utilize either the thermochemical reactions, sensible or latent heat capacity of materials to provide a heating or cooling resource, which can be replenished as required.

In this work, we present an overview of the most important energy storage technologies available or under development today. Among other aspects, the operating principles, and the most relevant characteristics of each technology are detailed. This paper also includes discussions on important criteria of energy storage technologies suitable for renewable energy applications.

2. Thermal energy storage (TES)

Thermal energy storage (TES) is widely recognized as a means to integrate renewable energies into the electricity production mix on the generation side, but its applicability to the demand side is also possible [20,21]. In recent decades, TES systems have demonstrated a capability to shift electrical loads from high-peak to off-peak hours, so they have the potential to become a powerful instrument in demand-side management programs. Thermal storage is a technology that ensures energy security, efficiency and environmental quality.

The thermal energy storage (TES) can also be defined as the temporary storage of thermal energy at high or low temperatures. TES systems have the potential of increasing the effective use of thermal energy equipment and of facilitating large-scale switching. They are normally useful for correcting the mismatch between