An Overview on Short and Long-Term Response Energy Storage Devices for Power Systems Applications

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Abstract. Energy storage devices provide valuable benefits to improve stability, power quality and reliability of supply. Storage technologies have developed significantly in order to meet the challenges of practical power systems applications.

Energy storage devices can be classified into short and long-term response, depending on their application. Technologies with high power density and with the ability to respond to the requests in short time fractions like flywheels, capacitors or superconducting magnetic coils belong to the so-called short-term response energy storage devices category. Energy storage devices with the capability to absorb and supply electrical energy for long periods of time like pumping hydro, batteries, compressed air and hydrogen fuel cells are considered in the long-term response category.

This paper concentrates on the latest short and long-term energy storage technology developments, performance analysis, and cost considerations.

Keywords

Energy storage, power systems balancing, energy management, renewable sources integration, voltage stability

1. Introduction

Power systems are experiencing significant changes in operational requirements that result from the sector restructure and evolution. Largely interconnected network, distributed and renewable generation lead to more complex and less secure power system operation.

Energy storage appears to be beneficial to utilities since it can decouple the instantaneous balancing between the demand and the supply. Therefore it allows the increased asset utilization, facilitates the penetration of renewable sources and improves the flexibility, reliability and efficiency of the grid.

However, the use of energy storage devices has not expanded significantly because of the state of technological developments and the price of energy storage devices which are still costly.

Nonetheless, there are several high performance storage technologies available today, or at an advanced state of development, which enables a new range of storage applications. For example, the issues related to the increasing integration of renewable sources in power systems have been one of the main drivers of this development.

Energy storage devices can be classified into two different categories, depending on their application: short-term response energy storage devices and long-term response energy storage devices.

Long-term response energy storage devices for power systems applications can usually absorb and supply electrical energy during minutes or hours and can specially contribute on the energy management, frequency regulation and grid congestion management.

Short-term response energy storage devices are usually applied to improve power quality, particularly to maintain the voltage stability in power systems, throughout a contribution during transients (few seconds or minutes).

2. Objectives and Methodology

This paper intends to present a survey on energy storage devices for power systems, focusing the distinction between short and long-term response technologies.

An operation description of the available energy storage technologies will be presented followed by some application cases.

The main contribution of this paper comes from the technology comparison with special attention given to characteristics like power and energy range, efficiency, life-time and costs.

3. Long-Term Response Energy Storage Devices

Sort of different long-term response energy storage technologies are already available today. A brief description of these main devices is presented below.

A. *Pumping hydro*

In pumping hydro storage, a body of water at a relatively high elevation represents a potential or stored energy. During peak hours the water in the upper reservoir is lead through a pipe downhill into a hydroelectric generator and stored in the lower reservoir. Along off-peak periods the water is pumped back up to recharge the upper reservoir and the power plant acts like a load in power system.

B. *Batteries*

Batteries store energy in electrochemical form creating electrically charged ions. When the battery charges, a direct current is converted in chemical energy, when discharges, the chemical energy is converted back into a flow of electrons in direct current form.

1) *Electrochemical*

Electrochemical batteries use electrodes both as part of the electron transfer process and store the products or reactants via electrode solid-state reactions.

2) *Redox Flow*

Redox flow batteries are storage devices that convert electrical energy into chemical potential energy by charging two liquid electrolyte solutions and subsequently releasing the stored energy on discharge.

C. *Compressed air*

In compressed air energy storage, off-peak hours power is taken from the grid and used to pump and compress air into a sealed underground cavern to a high pressure. The compressed air is mixed with natural gas and burnt together, in a conventional gas turbine. This method is actually more efficient as the compressed air will lose less energy.

D. *Hydrogen fuel cell*

During the operation of a fuel cell, hydrogen is ionized into protons and electrons at the anode, the hydrogen ions are transported through the electrolyte to the cathode by an external circuit (load). At the cathode, oxygen combines with the hydrogen ions and electrons to produce water. The hydrogen fuel cell system can be reversible, allowing electric power consumption for the production of hydrogen and that hydrogen can be stored for later use in the fuel cell.

4. Short-Term Response Energy Storage Devices

Short-term response energy storage devices should be used to aid power systems during the transient period after a system disturbance. The main short-term energy storage devices and their operation are presented below.

A. *Flywheels*

Flywheels store kinetic energy in a rotating mass. Such equipments have typically been used as short-term energy storage devices for propulsion applications such as powering train engines and road vehicles, and in centrifuges. In these applications, the flywheel smoothes the power load during deceleration by dynamic braking action and then provides a boost during acceleration.

B. *Supercapacitors*

Supercapacitors are electrochemical double layer capacitors that store energy as electric charge between two plates, metal or conductive, separated by a dielectric, when a voltage differential is applied across the plates.

C. *Magnetic Superconducting*

Superconducting magnetic energy storage (SMES) systems convert the ac current from a power system into the dc current flowing in the superconducting coil and store the energy in the form of magnetic field. The stored energy can be released to the ac system when necessary.

5. Conclusions and Perspectives

Energy storage devices provide valuable benefits to improve stability, power quality, and reliability of supply in power systems.

In this regard, this paper presents an overview on energy storage devices for power systems applications in the framework of a broader project that intends to project an energy storage system for facilities based on non-dispatchable renewable energies.

From the analysis performed, it is concluded that long-term energy storage devices like pumping-hydro and compressed air systems are the best suited for centered large-scale storage, on the other hand, batteries and hydrogen fuel cell systems space requirements and modularity place them as ideal solution for distributed energy storage.

Moreover, short-term response energy storage devices like supercapacitors are found to be well suited for use in power systems during transient periods that result from a system disturbance such as a line switching. Flywheels, with higher energy storage capacity look like the most appropriate to maintain voltage level and frequency, especially in power systems with considerable penetration of renewable energy like wind.

Further developments will focus on the dimensioning and development of an energy storage system for a Portuguese wind farm where short and long-term technologies will be combined.