Renewable and Sustainable Energy Reviews 25 (2013) 135–165

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Emergence of energy storage technologies as the solution for reliable operation of smart power systems: A review

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ARTICLE INFO

Article history:
Received 13 December 2012
Received in revised form
15 March 2013
Accepted 18 March 2013
Available online 20 May 2013

Keywords:
Flywheel energy storage
Electrochemical energy storage
Regenerative fuel cell
Pumped hydro energy storage
Supercapacitor energy storage
Compressed air energy storage
Smart power grid

ABSTRACT

The ever increasing penetration of renewable energy systems (RESs) in today deregulated intelligent power grids, necessitates the use of electrical storage systems. Energy storage systems (ESSs) are helpful to make balance between generation and demand improving the performance of whole power grid. In collaboration with RESs, energy storage devices can be integrated into the power networks to bring ancillary service for the power system and hence enable an increased penetration of distributed generation (DG) units. This paper presents different applications of electrical energy storage technologies in power systems emphasizing on the collaboration of such entities with RESs. The role of ESSs in intelligent micropower grids is also discussed where the stochastic nature of renewable energy sources may affect the power quality. Particular attention is paid to flywheel storage, electrochemical storage, pumped hydroelectric storage, and compressed air storage and their operating principle are discussed as well. The application of each type in the area of power system is investigated and compared to others.

Contents

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.03.056

1. Introduction

Modern social needs and optimal generation and/or consumption of electricity beside security issues in power networks, all together, present a new concept which is so-called "Smartgrid". Smartgrid integrates advanced sensing technologies, control methods and integrated communications into current electricity network. These features optimize the operation of whole power network making objective oriented balance between the generation, demand, environment and market constrains [1,2]. The deregulation of power systems leads to remarkable changes in operational requirements. Continuous increase of the energy demand and higher regional power transfers in a largely interconnected network lead to complex and less secure power system operation. Because of economic, technical and governmental limitations, the electricity generation and transmission facilities may not cope with such requirements. At the same time, the growth of electrical loads has made the quality of power supply a critical issue. Power system engineers have been challenging with these issues to find solutions allowing the system to be operated in a more flexible and controllable manner. Since the conventional power sources (synchronous generators) are high inertial equipments, their response to any disturbances within the power system is slow and sometimes they may not be able to keep the system stable. If high-speed real or reactive power control is available, load shedding or generator dropping may be avoided during disturbances. High speed reactive power control is possible through the use of flexible ac transmission systems (FACTS) devices. To provide the power grid with the fast real power control mechanism, real power can be circulated in the FACTS devices converter. However, a more reliable solution is to quickly vary the real power without affecting the system through the circulation of power. This is where energy storage technology can play a very prominent role in order to preserve the system stability and power quality. In this case, it is expected from the storage system to relief the consequences followed by rapidly damping oscillations, abrupt changes in load, and interrupting transmission or distribution systems [3,4].

The applications of, short-time medium to high power, energy storage system (ESS) in power quality control, traction and aerospace have been reported in [5]. One of the main concerns regarding the usage of intermittent renewable resources is the fluctuation of power which is generated by this kind. The power oscillation results in the power system instability and hence damages the equipments such as generators and motors. Using ESSs would be considered as a remedy to cope with this difficulty and balance the flow of power in the power network [6–9]. ESSs are also capable of correcting load voltage profiles with rapid reactive power control and thus allow the generators to keep their balance with the system load at their normal speed. Storage entities can also utilize voltage source converters (VSCs) to interrupt current and regulate voltage for utility networks. Energy storage is now seen more as a tool to enhance system stability, aid power transfer, and improve power quality in power systems [10,11].

2. Energy storage systems (ESSs) applications in power system

The role of energy storage systems in increasing the stability of distribution networks have been growing day by day. The most important benefit which is come up with ESSs is to support the power grid in order to fullfil its load demand constantly [12–14]. The role of ESSs is very important in growing renewable energy systems (RESs) penetration level, controlling the frequency, upgrading the transmission line capability, mitigating the voltage fluctuations and improving the power quality and reliability. Fig. 1 shows the power magnitude and the needed time for such applications. From the end-user view of point, ESSs should be able to provide maximum power about 7.5 MW for about 100 min in order to make flatten the load profile. For the short time applications, for example, to increase RESs depth of penetration at least 1 MW for more than 30 min is required to be received by the ESSs to make sure that the use of ESSs system is reasonable.

2.1. Increasing RESs depth of penetration

Although RESs are environmentally helpful, the intermittent nature of some types of RESs such as solar and wind may results in the power grid voltage and frequency oscillations. This matter leads to the widespread usage and replacement of fossil-fuel sources to supply the base-load demand. In this case, integration of RESs creates some new challenges on the operation of the power system such as potential unbalancing between the generation and load demand [12,15].

To resolve the problem followed by the intermittency of RESs, there is a need to support such entities by other conventional utility power plants [12,16]. It is expected that, for every 10% wind penetration, a balancing power from other generation sources equivalent to 2–4% of the installed wind capacity is always required for a power system to maintain its stability. The use of conventional power plants for this purpose makes the system more complex than where ESSs are utilized. This is serious for countries with a large penetration of solar and wind systems such as Denmark and Spain where about 20% and 10% of the electricity generation come from wind power, respectively [12].

A huge and reliable storage capacity can provides an opportunity to highly exploit intermittent nature renewable resources in collaboration with power grids to meet the requirements for a

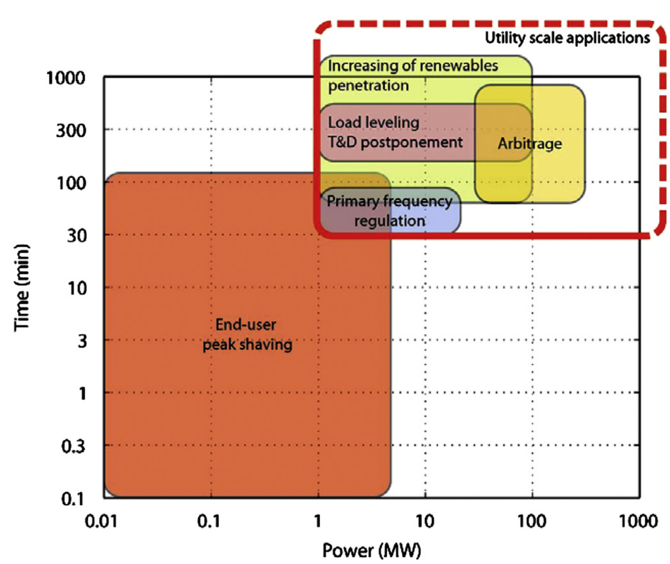

Fig. 1. Utility applications of ESS [12].