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ScienceDirect

Energy Procedia 73 (2015) 103 – 111

Energy Procedia

9th International Renewable Energy Storage Conference, IRES 2015

Hybrid energy storage systems for renewable energy applications

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Abstract

The paper gives an overview of the innovative field of hybrid energy storage systems (HESS). An HESS is characterized by a beneficial coupling of two or more energy storage technologies with supplementary operating characteristics (such as energy and power density, self-discharge rate, efficiency, life-time, etc.). The paper briefly discusses typical HESS-applications, energy storage coupling architectures, basic energy management concepts and a principle approach for the power flow decomposition based on peak shaving and double low-pass filtering. Four HESS-configurations, suitable for the application in decentralized PV-systems: a) power-to-heat/battery, b) power-to-heat/battery/hydrogen, c) supercap/battery and d) battery/battery, are briefly discussed. The paper ends with a short description of the HESS-experimental test-bed at Chemnitz University of Technology.

Peer-review under responsibility of EUROSOLAR - The European Association for Renewable Energy

*Keywords:*hybrid energy storage; battery; supercap, hydrogen; control; energy management; photvoltaics; power-to-heat

1. Introduction

The global problems of a rapidly rising CO_2-concentration in the atmosphere, the green-house effect and the related severe changes in world surface temperature and world climate have to be addressed and solved quickly. One important part of the solution will be a fast transition from the antiquated fossil-based energy system to a sustainable, 100%-renewable energy system. Therefore, a further and fast dissemination of PV and wind power is required. PV and wind power fluctuations on an hourly, daily and annual time scale (and with a regional distribution) can be handled, employing a variety of flexibility technologies, such as demand side management, grid extension or energy storage [1]. A number of storage technologies based on electrical, mechanical, chemical and thermal energy storage

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Peer-review under responsibility of EUROSOLAR - The European Association for Renewable Energy
doi:10.1016/j.egypro.2015.07.582

principles are available with quite different technical parameters and operating characteristics (s.Tab.1, [1], [2], [3]). Current system analysis studies indicate energy storage demand on a short-, mid- and long-term time scale [4], [5]. At this point, the utilization of the hybrid energy storage system (HESS) approach, integrating storage technologies with supplementary operating characteristics, can be very beneficial. Section 2 discusses typical HESS-applications, energy storage coupling architectures and basic energy management concepts. Section 3 introduces a principle power flow decomposition approach based on peak shaving and double low-pass filtering. Four HESS-configurations, suitable for the application in decentralized PV-systems: a) power-to-heat/battery, b) power-to-heat/battery/hydrogen, c) supercap/battery and d) battery/battery, are briefly discussed. The paper ends with a short description of the HESS-experimental test-bed at Chemnitz University of Technology.

Table 1.Comparison of different energy storage technologies.

	supercap	SMES	flywheel	lead-acid	lithium-ion	NaS	redox-flow	hydrogen	pumped hydro	CAES
energy density in Wh/l	2-10	0,5-10	**80-200**	50-100	**200-350**	**150-250**	20-70	**750/250bar 2400/liquid**	0,27-1,5	3-6
installation costs in €/kW	**150-200**	high	300	**150-200**	**150-200**	**150-200**	1000-1500	1500-2000	500-1000	700-1000
installation costs in €/kWh	10000-20000	high	1000	**100-250**	300-800	500-700	300-500	**0,3-0,6**	**5-20**	**40-80**
reaction time	**<10ms**	**1-10ms**	**>10ms**	**3-5ms**	**3-5ms**	**3-5ms**	>1s	10min	>3min	3-10min
self-discharge rate	up to 25% in first 48h	10-15 %/day	5-15 %/h	0,1-0,4 %/day	**5 %/month**	10 %/day	0,1-0,4 %/day	**0,003-0,03 %/day**	**0,005-0,02 %/day**	0,5-1 %/day
cycle life-time	**>1Mill.**	**>1Mill.**	**>1Mill.**	500-2000	**2000-7000**	**5000-10000**	**>10000**	>5000		
life-time in years	15	20	15	5-15	5-20	15-20	10-15	20	**80**	ca. 25
system efficiency in %	77-83	**80-90**	**80-95**	70-75	**80-85**	68-75	70-80	34-40	75-82	60-70
short-term (<1min)	**XXX**	**XXX**	**XXX**		X		X			
mid-term (>1min,<2d)			X	**XXX**	**XXX**	**XX**	**XX**	X	**XX**	**XX**
long-term (>2d)				X		X	**XX**	**XXX**	**XXX**	**XX**

2. Hybrid energy storage systems

In a HESS typically one storage (ES1) is dedicated to cover “high power” demand, transients and fast load fluctuations and therefore is characterized by a fast response time, high efficiency and high cycle lifetime. The other storage (ES2) will be the “high energy” storage with a low self-discharge rate and lower energy specific installation costs (s.Tab.1 and Fig.1).Main advantages of a HESS are:

- reduction of total investment costs compared to a single storage system (due to a decoupling of energy and power, ES2 only has to cover average power demand)
- increase of total system efficiency (due to operation of ES2 at optimized, high efficiency operating points and reduction of dynamic losses of ES2)
- increase of storage and system lifetime (optimized operation and reduction of dynamic stress of ES2)