Electrochemical Energy Storage/Conversion System

Subjects: Energy & Fuels

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Electrochemical energy storage and conversion systems such as electrochemical capacitors, batteries and fuel cells are considered as the most important technologies proposing environmentally friendly and sustainable solutions to address rapidly growing global energy demands and environmental concerns. Their commercial applications individually or in combination of two or more devices are based on their distinguishing properties e.g., energy/power densities, cyclability and efficiencies.

Electrochemical energy storage and conversion syst | electrochemical capacitors | batteries | fuel cells

1. Introduction

Comprehensive classification of electrochemical energy storage, conversion systems is shown in Figure 1, explain their basic working principles, and technical characteristics, highlight the distinctive properties of each system, and discuss their fields of application. A diverse range of energy storage and conversion devices is shown in Figure 1 based on their energy delivery time varying with the type of mechanism involved in energy storage or conversion systems. For example, electrochemical capacitors are considered as high power density devices and their delivery time is in the range of few seconds to minutes since these devices utilise only the material on the electrode surface unlike batteries or fuel cells where bulk of the material is involved in energy storage and conversion respectively. Other characteristics of these devices vary as well due to the fundamental difference in the mode of energy storage or conversion (physical/electrochemical). In case of electrochemical capacitors, most of the commercially used devices use electric double layer charge storage phenomenon, which results in inferior energy densities as compared to other electrochemical energy storage or conversion devices shown in Figure 2.

Figure 1. Classification of electrical energy storage and conversion devices.

Electrochemical capacitors/batteries and fuel cells are key electrochemical energy storage and conversion technologies respectively, used in commercial applications with their particular selection dependent on performance limitations such as energy densities, power densities, and cycle life.

Electrochemical batteries and fuel cells are considered as high energy density devices with typical gravimetric energy densities in the range of 100–200 Wh kg^{-1} and 600–1200 Wh kg^{-1} respectively, whereas current ECs have significantly lower energy densities with typical values typically between 0.05–30 Wh kg^{-1} [1]. However, ECs are considered as high-power density devices with very short charge/discharge times (of the order of seconds) which is difficult to achieve by other electrochemical energy storage and conversion devices. Figure 2 shows a comparison of specific energy, specific power and their delivery timescale for different energy storage and conversion devices. At present, none of these devices has the capability to meet the wide spectrum of requirements demanded by the diverse range of renewable energy sources such as wind, tidal and solar. However, they can respond to a broad rang requirements such as fast charge/discharge, peak power demands and high energy storage needs over a longer period of time when used in a combination of two or more.

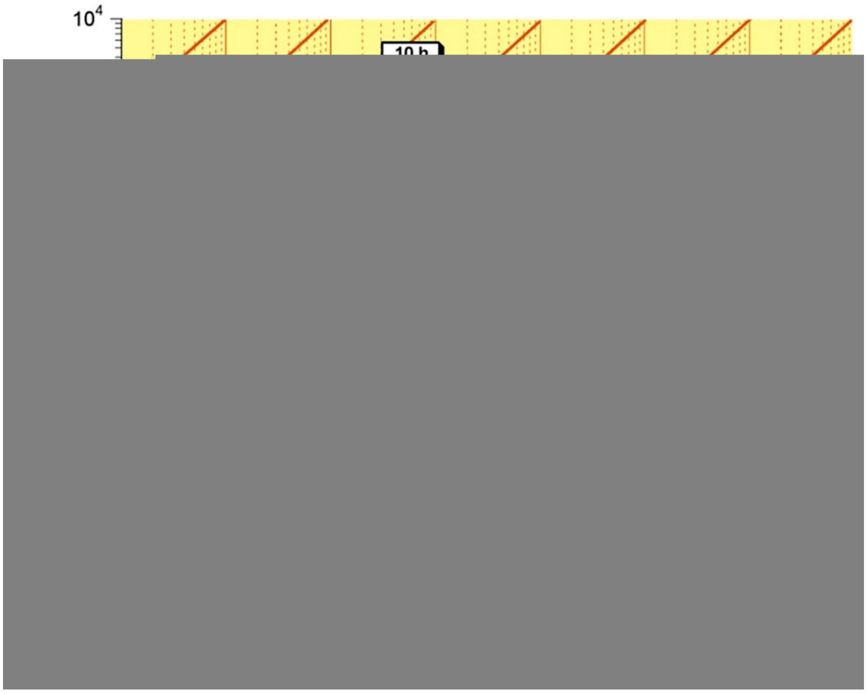

Figure 2. Energy density, power density and delivery timescale for different energy storage and conversion devices [2].

2. Comparison of Different Electrochemical Energy Storage and Conversion Systems

Energy storage/conversion devices perform two important tasks through time shifting bulk energy from renewables production to time of energy demand (supplied by batteries + fuel cells) and by production of clean, stable power and frequency, avoiding voltage spikes whish are important for digital economy by supercapacitors and high power batteries. Table 1 compares a number of fundamental characteristics of different electrochemical energy storage and conversion devices, such as electrochemical capacitors, batteries and fuel cells. It can be seen that electrochemical batteries and fuel cells are high energy density devices with typical gravimetric energy densities in the range of 75–200 Wh kg^{-1} and 800–1000 Wh kg^{-1} respectively. Conversely, electrochemical capacitors possess much lower energy densities, ranging from 10–230 Wh $kg^{−1}$, particularly in commercialised electric double layer capacitors where energy densities are in the range of 5–10 Wh $kg^{−1}$. Nevertheless, for high power density applications (i.e., power fluctuations, load shifting and short-term storage requiring fast charge/discharge). Furthermore, ECs are beneficial in applications requiring long cycle life and high efficiencies including backup power, safety and low maintenance applications such as uninterruptible power supplies (UPS) which results in improvements in power quality. However, the higher level of self-discharge in electrochemical capacitors when compared with other electrochemical devices is one of the major drawbacks which restricts their wider applications. On the contrary, electrochemical batteries and fuel cells are predominantly useful power sources for high energy density applications where the delivery is needed over longer period of time. Electrochemical batteries are more desirable in transportation and portable electronics applications since the technology is fully grown compared to FCs and ECs whereas other applications such as micro-grids, medical and power source for remote military installations where high power delivery is required over a sustained period with long cycle life is very vital makes

FCs more desirable choice. Other benefits using fuel cells is the use of secondary heat generated during their operations in applications such for combined heat and power (CHP) when driving micro gas turbines. Even though FCs are extremely useful power devices, they are still in testing phase and require R&D efforts to bring them in line with electrochemical batteries commercially. Electrochemical batteries are more useful and still maintain the highest market share in applications such as portable electronics, electric and hybrid electric vehicles due to scalability and the maturity of the technology [3][4][5][6].

Table 1. Technical characteristics of key energy storage and conversion technologies.

Technology	Specific Energy (Wh kg^{-1})	Specific Power (Wkg^{-1})	Life-Time (Years)	Cycle-Ability (Cycles)	Cyclic Efficiency (%)	Daily Discharge (%)
Different operating parameters of electrochemical capacitors						
EDLCs	6.8–12 [7]	65–10,200 [8]	<30 [9][10]	Up to 500,000 [11]	60–100 [12]	~25 [13]
PCs	23–67 [8]	21,000–220 [8]	5–9 [14]	Up to 5000 [12]	52–96 [15][16]	
HCs	132–231 [17]	2800–57 [17]	<10 [18]	12,000 [19]	80–95 [20][21]	
Different operating parameters of Batteries						
Lead-acid	25–50 [22]	10–400 [23]	5–15 [24]	200–1800 [25]	63–90 [26]	0.1–0.3 [23]
Li-ion	75–200 [23]	500–2000 [24]	14–16 [27]	Up to 20,000 [28]	75–90 [29]	1–5 [25]
NiCd	45–80 [30]	150–300 [23]	10–20 [23]	Up to 3500 [31]	60–83 [26]	0.2–0.6 [23]
NiMH	145–152 [32][33]	390–2000 [32][34]	<15 [35]	40,000 [35]	88–98 [32]	~1 [36]
VRB	10–30 [23]	166 [37]	5–20 [38]	≤12,000 [23]	75–85 [23][39]	Very low [25]
ZnBr	30–80 [23]	45–100 [40][41]	~10 [27]	≤2000 [60][23]	66–80 [83][26]	Small [42]
PSB	97–165 [43][44]	77–83 [45][46]	10–15 [23]	≤2000 [47]	93–95 [48]	~Zero [38]
Different operating parameters of Fuel cells						
SOFC	800–1000 [49]	200–1000 [50]	~4.5 [51]	50–1000 [52][53]	35–45 [54]	
PEMFC	500–1000 [55][56]	90–1000 [57][58]	~5 [59]	Up to 9000 [60]	53–58 [54]	
DMFC	Up to 1500 [61]	~1000 [62]	~10 [63]	300–10,000 [64]	~40 [54]	~Zero [66]

Technology	Specific Energy (Wh kg^{-1})	Specific Power (Wkg^{-1})	Life-Time (Years)	Cycle-Ability (Cycles)	Cyclic Efficiency (%)	Daily Discharge (%)
				[65]		

In case of electrochemical batteries short cycle life and inferior efficiencies are the drawbacks requiring attention. None of these technologies has the capability to fulfil all the requirements for very broad range of applications alone, a problem which can be overcome by using hybrid systems consisting of combination of two or more of these devices, with ability to respond to applications with more complex requirements (e.g., in EVs/HEVs where high energy density batteries or fuel cells are coupled with high power capable ECs). Such combinations will result in longer overall system life, performance improvements and design flexibility, since batteries or fuel cells will not be pushed to the limits of their power capabilities and edge of their stabilities and response time Comprehensive details of technical characteristics of different electrochemical energy storage and conversion devices are listed in Table 1 above.

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