ORIGINAL PAPER

ENERGY STORAGE SYSTEMS

ELENA RADUCAN, LUMINITA MORARU

Dunarea de Jos University of Galati, Faculty of Sciences, 800201, Galati, Romania

Abstract. *In this paper you will find an overview of systems and energy storage techniques and a comparison of the important characteristics of them. Delocalized electricity production and the introduction of variable, fluctuating sources (renewable energy: solar, wind turbines, etc.) increase the difficulty of stabilizing the power network, mainly due to a supply-demand imbalance. It is therefore convenient to generate the energy, transmit it, convert it, and then store it if need be. More than ever then, the storage of electrical energy has become a necessity.*

Keywords: *energy, technology, storage.*

1. INTRODUCTION

Electrical energy is an invisible, omnipresent commodity that is readily available at the lowest possible cost in most cases. It has long been considered a common consumer good. Today, it makes up 12% of the total energy processed by humanity, a proportion that is expected to grow over the next few years (34% predicted for 2025) in a context of diminishing fossil fuels, growing use of renewable energy, and greater respect for the environment.

At present, the production of electricity is highly centralized and, often, a long distance away from its end users. Load levelling is initially based on the prediction of daily and seasonal needs, but also, when production is not sufficient, on the contribution of secondary modes like hydraulic and thermal plants. In fact, these plants also use stored energy: water for the pumped storage plants, and fossil fuels for the thermal plants [1].

Nanotechnology offers, for the first time, tools to develop new industries based on cost-effective and cost-efficient economies, thus seriously contributing to a sustainable economic growth. Nanotechnology is a broad term typically used to describe materials and phenomena at nanoscale, on the scale of 1 billionth to several tens of billionths of a meter [2].

2. ENERGY STORAGE SYSTEMS

2.1. PUMPED HYDRO STORAGE (PHS)

Pumped storage hydroelectricity is a type of hydroelectric power generation used by some power plants for load balancing. The method stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest. Pumped storage is the largest-capacity form of grid energy storage now available.

2.2. THERMAL ENERGY STORAGE (TES)

Thermal energy storage may refer to a number of technologies that store energy in a thermal reservoir for later reuse. They can be employed to balance energy demand between

Corresponding author: luminita.moraru@ugal.ro

day time and night time. The thermal reservoir may be maintained at a temperature above (hotter) or below (colder) than that of the ambient environment.

2.3. COMPRESSED AIR ENERGY STORAGE (CAES)

Compressed Air Energy Storage (CAES) refers to the compression of air to be used later as an energy source. At utility scale, it can be stored during periods of low energy demand (off-peak), and for use in meeting periods of higher demand (peak load). Alternatively it can be used to power tools, or even vehicles.

2.4. ENERGY STORAGE COUPLED WITH NATURAL GAS STORAGE (NGS)

The idea is to couple underground natural gas storage with electricity storage. The pressure difference between high-pressure gas storage (~ 200 bars) in reservoirs deep underground (1500 m) and gas injected into the conduits with a maximum service pressure of 60–80 bars leads to the consumption of energy for compression, energy that could be released in the form of electricity during decompression [1].

2.5. ENERGY STORAGE USING FLOW BATTERIES (FBES)

Flow batteries are a two-electrolyte system in which the chemical compounds used for energy storage are in liquid state, in solution with the electrolyte. They overcome the limitations of standard electrochemical accumulators (lead–acid or nickel–cadmium for example) in which the electrochemical reactions create solid compounds that are stored directly on the electrodes on which they form. This is therefore a limited-mass system, which obviously limits the capacity of standard batteries [1].

2.6. FUEL CELLS-HYDROGEN ENERGY STORAGE (FC-HES)

Fuel cells are self-contained, power-generation devices that are able to produce reliable electricity for residential, commercial, industrial and transportation applications. A fuel cell can convert hydrogen directly into electricity that can be used to power an electric car, for example, or a home.

2.7. CHEMICAL STORAGE

Chemical storage is achieved through accumulators. These systems have the double function of storage and release of electricity by alternating the charge–discharge phases. They can transform chemical energy generated by electrochemical reactions into electrical energy and vice versa, without harmful emissions or noise, and require little maintenance [1].

2.8. FLYWHEEL ENERGY STORAGE (FES)

Flywheels have been around for thousands of years. The earliest application is likely the potter’s wheel. Perhaps the most common application in more recent times has been in internal combustion engines. A flywheel is a simple form of mechanical (kinetic) energy storage. Energy is stored by causing a disk or rotor to spin on its axis. Stored energy is proportional to the flywheel’s mass and the square of its rotational speed.

2.9. Superconducting magnetic energy storage (SMES)

In a Superconducting Magnetic Energy Storage (SMES) system, energy is stored within a magnet that is capable of releasing megawatts of power within a fraction of a cycle to replace a sudden loss in line power.

2.10. Energy storage in supercapacitors

EDLCs (Electric Double Layer Capacitors) store electrical charge in a similar manner to the conventional capacitors, but the charges do not accumulate on two conductors. Instead the charges accumulate at the interface between the surface of a conductor and an electrolytic solution. The accumulated charges hence from an electric double-layer, the separation of each layer being of the order of a few Angstroms [3].

Supercapacitor are electrochemical capacitors that have an unusually high energy density when compared to common capacitors, typically on the order of thousands of times greater than a high capacity electrolytic capacitor.

3. COMPARISON OF THE DIFFERENT STORAGE SYSTEMS

3.1. TECHNOLOGY COMPARISONS

Each technology has some inherent limitations or disadvantages that make it practical or economical for only a limited range of applications.

Tabel 1. Technology comparison [3]

Storage Technologies	Main Advantages (relative)	Disadvantages (relative)	Power Apllication	Energy Apllication
Pumped storage	High capacity, low cost	Special site requirement		●
CAES	High capacity, low cost	Special site requirement, need gas fuel		●
Flow batteries: PSB VRB ZnBr	High capacity, independent power and energy ratings	Low energy density	◑	●
Metal-Air	Very high energy density	Electric charging is difficult		●
NaS	High power and energy density, high efficiency	Production cost, safety concerns (addressed in design)	●	●
Li-Ion	High power and energy density, high efficiency	High production cost, requiers special charging circuit	●	○
Ni-Cd	High power and energy density efficiency		●	◑
Other advanced batteries	High power and energy density, high efficiency	High production cost	●	○
Lead-Acid	Low capital cost	Limited cycle life	●	○
Flywheels	High power	Low energy density	●	○
SMES, DSMES	High power	Low energy density, high production cost	●	
E.C. Capacitors	Long cycle life, high efficiency	Low energy density	●	◑

Note. ●-fully capable and reasonable; ◑- reasonable for this application; ○- feasible but not quite practical or economical; None – not feasible or economical.

3.2. RATINGS

Large -scale stationary applications of electric energy storage can be divided in three major functional categories:

1. Power Quality. Stored energy, in these applications, is only applied for seconds or less, as needed, to assure continuity of quality power.

2. Bridging Power. Stored energy, in these applications, is used for seconds to minutes to assure continuity of service when switching from one source of energy generation to another.

3. Energy Management. Storage media, in these applications, is used to decouple the timing of generation and consumption of electric energy. A typical application is load levelling, which involves the charging of storage when energy cost is low and utilization as needed. This would also enable consumers to be grid-independent for many hours.

Although some storage technologies can function in all application ranges, most options would not be economical to be applied in all three functional categories (see Fig.1).

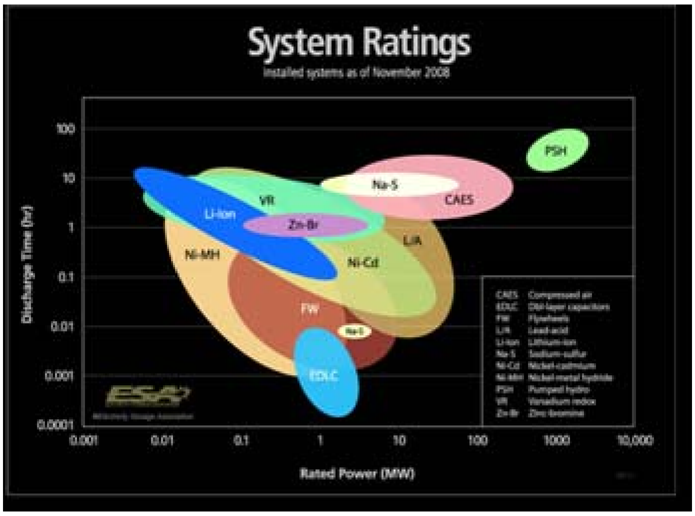

Fig. 1. System ratings [3].

3.3. SIZE AND WEIGHT

Size and weight of storage devices are important factors for certain applications. Metal-air batteries have the highest energy density in this chart. However, the electrically rechargeable types, such as zinc-air batteries, have a relatively small cycle life and are still in the development stage. The energy density ranges reflect the differences among manufacturers, product models and the impact of packaging (see Fig. 3).

3.4. CAPITAL COSTS

While capital cost is an important economic parameter, it should be realized that the total ownership cost (including the impact of equipment life and O&M costs) is a much more meaningful index for a complete economic analysis. For example, while the capital cost of lead-acid batteries is relatively low, they may not necessarily be the least expensive option for energy management (load levelling) due to their relatively short life for this type of application. The battery costs in this chart have been adjusted to exclude the cost of power conversion electronics. The cost per unit energy has also been divided by the storage efficiency to obtain the cost per output (useful) energy. Installation cost also varies with the type and size of the storag (see Fig.2).

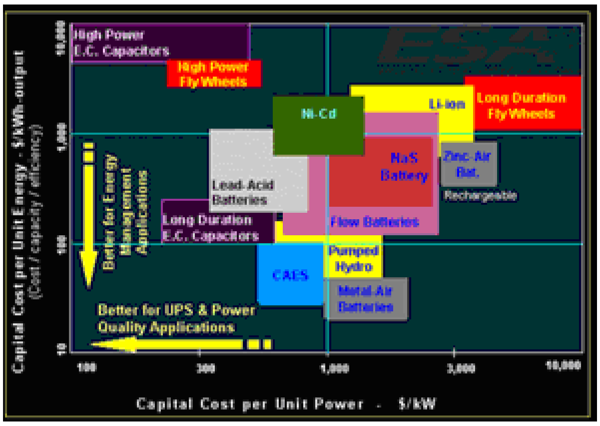

Fig. 2. Distribution of storage techniques as a function of investment costs per unit of power or unit of energy [1].

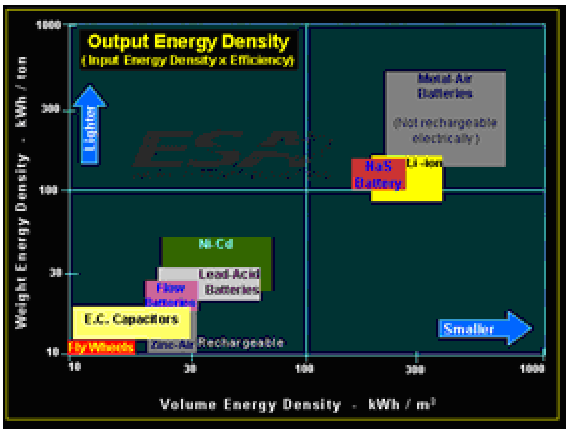

Fig. 3. Energy density ranges

3.5. LIFE EFFICIENCY

Efficiency and cycle life are two important parameters to consider along with other parameters before selecting a storage technology. Both of these parameters affect the overall storage cost. Low efficiency increases the effective energy cost as only a fraction of the stored energy could be utilized. Low cycle life also increases the total cost as the storage device needs to be replaced more often (see Fig. 4)[3].

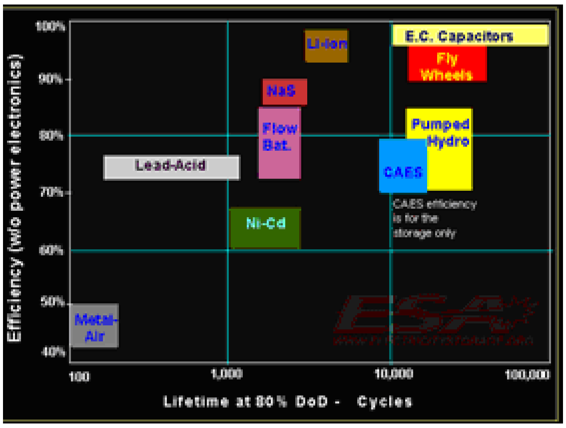

Fig. 4. Distribution of storage techniques techniques as a function of energy efficiency and life expectancy [1].

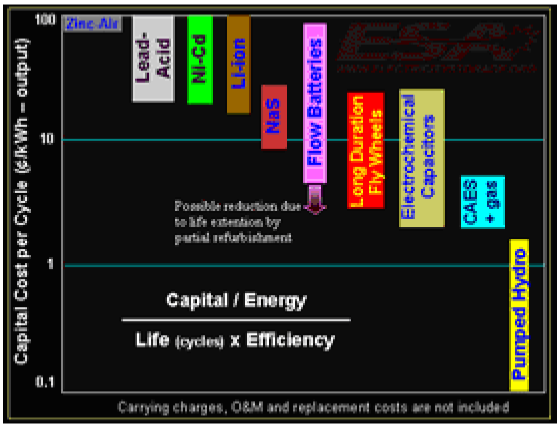

Fig. 5. Distribution of storage techniques techniques as a function of investment costs calculated per charge-discharge cycle [1].

3.6. PER-CYCLE COST

Per-cycle cost can be the best way to evaluate the cost of storing energy in a frequent charge/discharge application, such as load levelling. This chart shows the capital component of this cost, taking into account the impact of cycle life and efficiency. For a more complete per-cycle cost, one needs to also consider O&M, disposal, replacement and other ownership expenses, which may not be known for the emerging technologies. It should be noted that per-cycle cost is not an appropriate criterion for peak shaving or energy arbitrage where the application is less frequent or the energy cost differential is large and volatile (see Fig.5) [3].

4. CONCLUSIONS

The possibility of storing electrical energy exists, whenever and wherever they are needed, and in any quantity. Storage is the weakest link of the energy domain, but is a key element for the growth of renewable energies. When the energy source is intermittent and located in an isolated area which cannot be connected to the distribution network, storage becomes crucial. This need is not as obvious when the source of energy is connected to the network (as is the case for wind turbines and photovoltaic systems in industrialized countries) but storage could become unavoidable in the future. Indeed, with the opening of the energy market, many delocalized sources, usually intermittent renewable sources, will be connected to the network, which could lead to destabilization. To overcome this problem, storage and sound management of these resources are the best solutions [1].

Acknowledgements: *The authors acknowledge the partly financial support of the grant POSDRU 6/1.5/S/15.*

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Manuscript received: 30.04.2010
Accepted paper: 17.10.2010